Final Report on 2003 Airborne Geophysical Survey at Pueblo of Isleta Bombing Targets, New Mexico

February 14 – February 26, 2003

ESTCP Projects 200037 and 37

Revision 1

October 2005

Prepared by

Environmental Sciences Division
Oak Ridge National Laboratory

ESTCP

Environmental Security Technology Certification Program

ornl

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
10-2005	Final	02-2003 to 10-2005

4. TITLE AND SUBTITLE
Final Report on 2003 Airborne Geophysical Survey at Pueblo of Isleta Bombing Targets, New Mexico

5a. CONTRACT NUMBER
W31RYO10402655

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Les P. Beard
William E. Doll
T. Jeffrey Gamey

5d. PROJECT NUMBER
200037 and 37

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Oak Ridge National Laboratory
Bethel Valley Road
Oak Ridge, TN 37830

8. PERFORMING ORGANIZATION REPORT NUMBER
n/a

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program
901 North Stuart Street
Suite 303
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
n/a

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A: Approved for Public Release, Distribution is Unlimited

13. SUPPLEMENTARY NOTES
n/a

14. ABSTRACT
This report describes the results of a low altitude helicopter geophysical survey performed by U.S. Army Engineering Support Center, Huntsville (USAESCH) and Oak Ridge National Laboratory (ORNL) over areas contaminated by unexploded ordnance on Pueblo of Isleta Nation lands in February, 2003. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. A survey was carried out at area S-01 on the Pueblo of Isleta where the Department of Defense previously had conducted weapons tests and bombing exercises. Area S-01 comprised about 660 hectares (1630 acres). The average rate of coverage for site S-01 was 39 ha/hr and the average survey speed was 15 m/s. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was about 1 m. Noise levels of magnetometers fell within acceptable levels, usually less than 1 nT. At site S-01, 78% of all non-seed ordnance items (double-blind test) and 46% of seed items (blind test) were detected.

15. SUBJECT TERMS
airborne, magnetic, UXO

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	UU	76

19a. NAME OF RESPONSIBLE PERSON
William E. Doll

19b. TELEPHONE NUMBER *(Include area code)*
865-483-2548

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Table of Contents

Acronym List

AGL	Above ground level
AS	Analytic signal
ASCII	American Standard Code for Information Interchange
ADU	Attitude determination unit
BBR	Badlands Bombing Range, South Dakota
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data analysis system
DoD	Department of Defense
DQO	Data Quality Objective
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
GIS	Geographic Information System
GPS, DGPS	(Differential) Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
INS	U.S. Immigration and Naturalization Service
IDA	Institute for Defense Analyses
MTADS	Multi-Sensor Towed Array Detection System
NAD	North American Datum
NRL	Naval Research Laboratory
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
RMS	Root-mean-square
SERDP	Strategic Environmental Research & Development Program
STC	Supplemental Type Certificate
TIF, GeoTIF	(Geographically referenced) Tagged Information File
TF	Total (magnetic) field
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

List of Figures

List of Tables

Acknowledgments

This work was funded by the Environmental Security Technology Certification Program under the direction of Dr. Jeffrey Marqusee and Dr. Anne Andrews, and supported by Mr. Scott Millhouse at the U.S. Army Corps of Engineers Mandatory Center of Excellence for Ordnance and Explosives, Huntsville, Alabama. The report was written by employees of Oak Ridge National Laboratory. Oak Ridge National Laboratory is managed by UT-Battelle, LLC for the U.S. Department of Energy under contract DE-AC05-00OR22725. A contractor of the U. S. Government has authored the submitted manuscript. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes. We thank the residents of the Pueblo of Isleta for allowing access to the Pueblo of Isleta Reservation where the test sites are located.

Abstract

This report describes the results of a low altitude helicopter geophysical survey performed by U.S. Army Engineering Support Center, Huntsville (USAESCH) and Oak Ridge National Laboratory (ORNL) over areas contaminated by unexploded ordnance on Pueblo of Isleta Nation lands in February, 2003. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. A survey was carried out at area S-01 on the Pueblo of Isleta where the Department of Defense previously had conducted weapons tests and bombing exercises. Area S-01 comprised about 660 hectares (1630 acres). The average rate of coverage for site S-01 was 39 ha/hr and the average survey speed was 15 m/s. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was about 1 m. Noise levels of magnetometers fell within acceptable levels, usually less than 1 nT. At site S-01, 78% of all non-seed ordnance items (double-blind test) and 46% of seed items (blind test) were detected. The average detection rate of all ordnance items using a 2m search radius was 70% with a nominal false positive rate of 14% of the total number of excavations. The target location accuracy at this search radius was 103cm with a 45cm standard deviation. Ordnance items with peak-to-peak anomalies of more than 5.5 nT stand out clearly above background noise, which in outlying areas was usually less than 2 nT. In more cluttered areas, items were frequently missed when the total magnetic field anomaly fell below about 5 nT.

1.0 Introduction

1.1 Background

Portions of lands belonging to the Pueblo of Isleta Nation have been contaminated with unexploded ordnance (UXO) through Department of Defense (DoD) activities, e.g. during training exercises or during weapons tests. As there was no clear understanding as to the nature and extent of the UXO contamination, a low-altitude airborne geophysical survey was conducted in order to demonstrate its efficacy as an economical rapid reconnaissance tool at UXO sites.

This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over UXO-contaminated areas on Pueblo of Isleta tribal lands. The area surveyed, located southwest of Albuquerque, New Mexico, is designated S-01. Supplemental data were also acquired over a temporary calibration site. Surveys were flown so as to completely cover the area of the suspected bombing targets.

The survey, which included test flights for airworthiness certification, was conducted from February 6 to February 28, 2003. Mobilization of U.S. and Canadian-based crews began on February 6, from Susanville, California, where an ORAGS geophysical survey of portions of the Sierra Army Depot had been conducted. Upon arrival of the aircraft and crew, test flights began for Supplemental Type Certification (STC) for the ORAGS vertical gradient and total field systems. STC testing required four days of flights and installations. Test and compensation flights took place on February 13. Total magnetic field data were collected between February 14-19, and on February 21, and February 25. The helicopter was down for weather on February 20 and for repair of a failed compressor during February 22-24. Upon de-installation, the ORNL team and equipment arrived in Oak Ridge, TN on February 28.

1.2 Objectives of the Demonstration

The objectives of the demonstration survey are:

- To provide a means of determining the improvement resulting from recent modification in the Oak Ridge Airborne Geophysical System (ORAGS) total field magnetometry system;
- To assess the capabilities of the system at a site representing conditions and ordnance types typically found on former DoD ranges;
- To detect and map UXO and UXO-related items for subsequent clearance actions.

The survey was accomplished using the ORAGS Arrowhead magnetometer array.

1.3 Regulatory Drivers

UXO clearance is generally conducted under CERCLA authority. In spite of the lack of specific regulatory drivers, many DoD sites and installations are pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. buried waste sites or ordnance caches) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for the application of technologies in advance of future regulatory drivers and mandates.

1.4 Stakeholder/End-User Issues

The Pueblo of Isleta sites are Formerly Used Defense Sites and as such it is important that concentrations of ordnance and locations of possibly live ordnance be mapped so that actions can be taken toward removal of UXO or safeguards can be established where there is the possibility that live ordnance is still in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology is expected to contribute to the performance of these activities in terms of efficiency as well as cost.

2.0 Technology Description

2.1 Technology Development and Application

The total field system is a fourth-generation airborne magnetometer array (Figures 2.1 and 2.2) that has been designated the ORAGS-Arrowhead system. Changes from the previous ORNL airborne magnetometer array, the ORAGS-Hammerhead, include a new boom architecture designed to position sensors at low-noise locations, and a new aircraft orientation system. The new attitude determination unit (ADU) is based on four Global Positioning System (GPS) antennas rather than fluxgate magnetometer measurement as in previous generations. For the ORAGS-Arrowhead system, four magnetometers at 1.7-meter spacing are located in a forward V-shaped boom assembly, and two magnetometers with equivalent spacing are located in each of the lateral booms. Although the spacing is similar to that of the predecessor ORAGS-Hammerhead system, moving two magnetometers that were previously the innermost rear boom magnetometers on the Hammerhead system to the forward boom assembly of the Arrowhead improved noise conditions over those of the Hammerhead system.

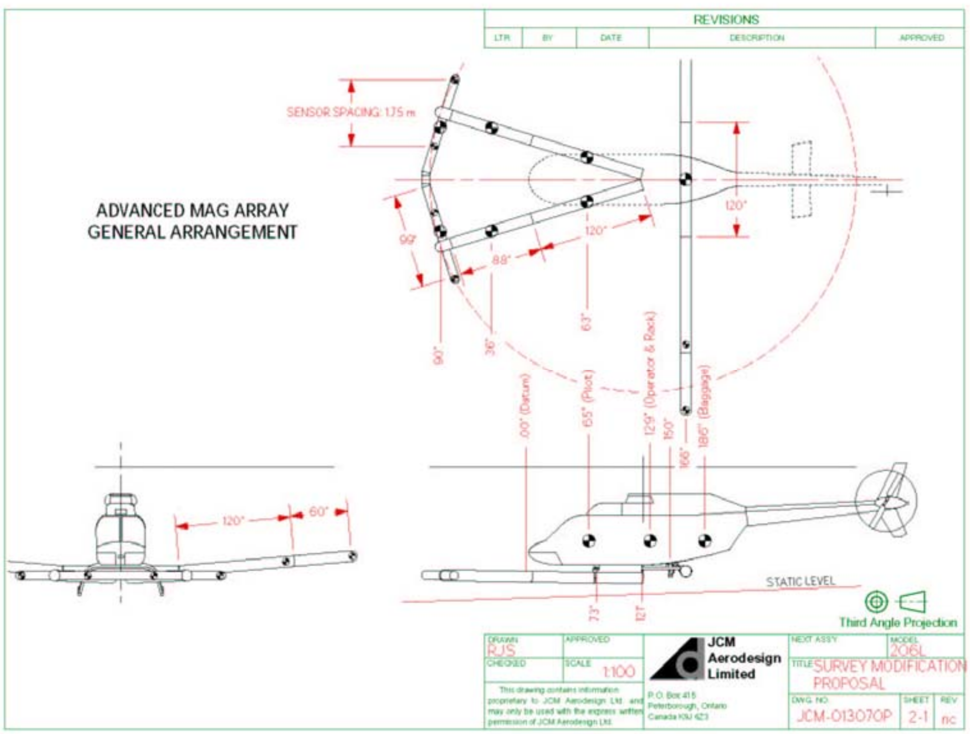

Figure 2.1 Schematic for the ORAGS-Arrowhead airborne total field magnetometer system that has been constructed to evaluate the improvements over previous generations of total field systems.

Figure 2.2 ORAGS-Arrowhead helicopter total field magnetometry system at site S-01.

2.2 Previous Testing of the Technology

ORNL has previously tested two generations of boom-mounted airborne magnetometer systems for UXO detection and mapping. The first system tested was the HM-3 system, depicted in Figure 2.3, developed by Aerodat, Ltd., under the direction of J.S. Holladay and T. J. Gamey. The 1999 airborne magnetometer tests at BBR deployed this system, operated by High Sense Geophysics, and the system was subsequently modified to meet ORNL requirements (Gamey et al., 2000).

In September 2000, ORNL deployed a more advanced helicopter system at the Badlands Bombing Range (BBR), the ORAGS-Hammerhead system, in cooperation with Dr. Holladay (now at Geosensors Inc.) and Mr. Gamey (now at ORNL). While somewhat similar in appearance to the HM-3 system, this system, illustrated in Figure 2.4, is significantly improved in terms of the number of magnetometers, magnetometer spacing, system positioning, navigation, and data acquisition parameters (Doll et al., 2001; Gamey et al., 2001). Additionally, a dihedral in the boom tubes improved system safety by raising the boom tips.

Figure 2.3 The HM-3 helicopter magnetometry system used by ORNL in 1999 for surveys at Badlands Bombing Range.

Figure 2.4 ORAGS-Hammerhead airborne magnetometer system used at Badlands Bombing Range in FY2000.

2.3 Factors Affecting Cost and Performance

The cost of an airborne survey depends on several factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site and fuel costs, among other factors.
- The total size of the blocks to be surveyed
- The length of flight lines
- The extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives which dictate survey altitude and number of flight lines
- The temperature and season, which control the number of hours that can be flown each day
- The location of the site, which can influence the cost of logistics
- The number of sensors and their spacing; systems with too few sensors may require more flying, particularly if they require interleaving of flight lines
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction

2.4 Advantages and Limitations of the Technology

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at considerably lower cost than ground-based systems. Current cost models for production surveys indicate that the survey cost may approach $70.00 per acre under optimal conditions. Small research-oriented projects such as this survey have necessarily higher costs per acre. Furthermore, airborne data may be acquired and processed in a shorter period of time, thereby reducing the time required for reviewing large areas. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation limits the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items.

3.0 Demonstration Design

3.1 Performance Objectives

Shown in Table 3.1 is a listing of the various performance objectives for this survey.

Table 3.1 – Performance Objectives of Arrowhead Airborne Magnetic System

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Qualitative	Total Field (TF) system aerodynamically stable	Pilot report	Yes
Quantitative	TF system has lower noise than predecessors	Comparison of data sets at test site and elsewhere	Yes
Qualitative/Quantitative	New attitude measurement system provides improved sensor positioning	Comparison of ground follow-up results for target reacquisition radius and comparison of processed results over small known targets	Yes, however difficulties with ADU caused much data to have only marginally improved accuracy.
Qualitative/Quantitative	Improved aircraft compensation over previous systems	Comparison of Figure of Merit (FOM) and compensated profiles with those from Hammerhead system data	6.4 nT (see digital Appendix H)
Quantitative	Probability of detection	>90%	No, 70%
Quantitative	False alarm rate	6%	No, 14%
Quantitative	Location accuracy	<60 cm	No, 103 cm.
Quantitative	Survey rate	>40 acres/hr	Yes, 96 ac/hr
Quantitative	Percent site coverage	100%	Yes, 100%

3.2 Selecting Test Sites

The airborne survey site was chosen to enable, where possible, direct comparison of results from the new generation airborne systems with results of ground-based geophysical systems for UXO detection and mapping. Airborne data were acquired at site S-01 at Pueblo of Isleta. The survey site for this demonstration project is a bombing target on the Pueblo of Isleta. The site was remote, but accessible by both road and air, and was found to contain significant ordnance debris at the surface.

3.3 Test Site History/Characteristics

The sites selected within the Pueblos of Isleta are Formerly Used Defense Sites (FUDS) located west of Albuquerque in New Mexico. Totaling more than half a million acres, large portions of this typically western desert environment are flat and devoted to ranching. The remaining portions of land are gently rolling to nearly vertical in appearance that have been formed by the extensive erosion of the soft fine-grained underlying sediments, creating canyons, washes, and gullies.

The Pueblo is situated on the eastern edge of the New Mexico portion of the Colorado Plateau, east of the Albuquerque-Belen Basin. Separating the geologic provinces is a series of strong north-south trending high-angle faults stepping downward from the plateau into the basin. The geology of the area is dominated by both consolidated and unconsolidated units and includes sandstone, mudstone, claystone, and shale. Igneous basalt formations cap the mesas in the area. Typical elevations at the sites are 1500-1800 meters above sea level.

With regard to historical ordnance, numerous sites exist across the entire area that were utilized for aerial bombardment activity, including the target area identified for this demonstration. From visual inspection, the principal ordnance type present at the Pueblo of Isleta sites is the M38 practice bomb. Evidence of this ordnance item is present on the surface at all sites under consideration for this demonstration, and several hundred M38s excavated during the Pueblo of Laguna MTADS demonstration (McDonald and Nelson, 1999).

3.4 Present Operations

Pueblo of Isleta site S-01 was surveyed by ORNL in the spring of 2002. Site S-01 was also surveyed in February-March, 2003 by NRL using airborne and ground MTADS (Nelson et al., 2004) under the guidance of the ESTCP Program Office. No remediation work had been done at the site prior to the MTADS survey.

3.5 Pre-Demonstration Testing and Analysis

Shakedown testing of the assembled airborne system and associated components was conducted in Toronto, Ontario, Canada during December 10-21, 2001. These tests were used to determine whether the completed system and its components were performing as designed.

The airborne magnetic system was flight tested by an aeronautical engineer and determined to be completely flightworthy. The testing validated both the aerodynamic stability and performance of the system. Magnetic noise levels for the system were measured both on the ground and during flight. Total magnetic field data were collected at low altitude over known targets in a seeded test area.

The test of the ORAGS-Arrowhead total magnetic field array demonstrated a significant reduction in ambient noise from the previous ORAGS-Hammerhead configuration. The two sensors located 2.6 meters from the centerline of the helicopter showed 50% reduction in peak-peak rotor noise without compromising the efficiency of the aerodynamics or the quality of the data from the other sensors. In the high noise environment of the helicopter, relative noise levels between sensors were used to demonstrate this reduction. The conclusion is that the new sensor positions show a clear reduction in rotor noise relative to the previous array configuration.

In summary, all system components in both airborne systems performed as anticipated. The reduction in noise at the inboard positions 2.6 meters from the centerline of the helicopter is somewhat higher than the noise levels of the other magnetometers, but is reduced over inboard magnetometers from the ORAGS-Hammerhead system. Flight performance and maneuverability were excellent with no ballast required that would reduce flight time.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

Mobilization involved packing and transporting all system components by trailer to Albuquerque and installing them on a Bell 206L Long Ranger helicopter. Calibration and compensation flights were conducted and results evaluated. The eight cesium magnetometers, ADU, GPS systems, fluxgate magnetometers, data recording console, and laser altimeter were tested to ensure proper operation and performance. The Mission Plan was read and signed by all project participants to assure safe operation of all systems.

3.6.2 Period of Operation

Mobilization of the geophysical crew and the flight crew from Susanville, California began on February 6, 2003. This required two days travel to Albuquerque for the geophysical equipment trailer. Installation began the morning of February 8. Test flights for FAA flight certification for the Arrowhead total field system and the magnetic vertical gradient system were carried out from February 9 through February 12. Test and compensation flights took place on February 13. Total magnetic field data were collected at area S-01 during February 14-19, and on February 21, and February 25. The helicopter was down for weather on February 20 and for repair of a failed compressor during February 22-24. De-installation began in the afternoon of February 26, and the geophysical and air crews departed for Oak Ridge and Toronto, respectively.

3.6.3 Area Characterized

The S-01 survey area comprised 660 ha. At the site, 100 percent coverage of the target area was attained using 12-m flight line spacing, and sensor spacing of about 1.7 m.

3.6.4 Residuals Handling

This section does not apply to this project and report.

3.6.5 Operating Parameters for the Technology

The ORAGS Arrowhead system is designed for daylight operations only. Lines were flown in a north-south pattern with nominal 12m flight line spacing for the high density survey coverage. Binary data from the eight magnetometers was recorded on the console at a rate of 1200 samples per second. Typical survey speeds for the system were 80-100 km/hr. Survey height was 1-3 m above ground level. In areas where background magnetic susceptibility and variation is small, vegetation height low, and topographic change gradual, the system can be expected to detect anomalies as small as 2 nT. These thresholds can be expected to increase as any of the aforementioned variables increase. Furthermore, pitch and roll of the helicopter can cause sensors to be closer or further from the ground and target than is the case in level flight, and this can also produce anomalies in excess of 2 nT.

3.6.6 Experimental Design

The test conducted with the ORAGS-Arrowhead total magnetic field system is summarized in Table 3.2.

Table 3.2 - Field Tests with Arrowhead Total magnetic field System

Test ID	Description	Parameters	Sites
Standard configuration	Test overall system performance (aerodynamics, noise, compensation, positioning, orientation, detection)	Nominal altitude = 2m	Full survey coverage of Pueblo of Isleta site S-01.

Data quality objectives (DQOs) to be used for this technology demonstration were based on prior-generation airborne results as the baseline performance condition, as well as previous MTADS demonstration data. Analysis of prior-collected airborne data by the HM-3, shown in Figure 2.3, yielded preliminary results of 89% ordnance with 6% false positives (Doll et al., 1999). Analysis by the Institute for Defense Analyses (IDA) of the same ORNL data sets yielded slightly different results (78% to 83% ordnance, 17% to 24% false positives).

Subsequent airborne surveys at BBR, Shumaker Naval Ammunition Depot and Rocket Test Range, Nomans Land Island, and New Boston Air Force Station yielded results consistent with the previous surveys at BBR. One difference is that positional accuracy of the data has improved from approximately 2m in earlier tests to about 1m in this test. This results from inclusion of a GPS-based orientation measurement system.

Given the various considerations associated with both the interpretation of airborne geophysical survey data and the calculations of the various performance parameters, DQOs for the demonstration of the Arrowhead total field system approached or met the current performance parameters. ORNL expected the ORAGS-Arrowhead total field system to provide detection in the vicinity of 90% ordnance with 5% to 7% false positives. The methodologies used to acquire the airborne data are described in previous sections of this document. All surveys conducted with the Arrowhead total field system were performed as high-density surveys with line spacing established to account for sensor positions such that no gaps or voids exist in any data set, except where topography, vegetation, or cultural features precluded tight line spacing. Positioning for the anomalies detected, being about 100 cm, fell short of the performance metric of 60 cm.

Data processing procedures
The 1200 Hz raw data were desampled in the signal processing stage to a 120 Hz working data set recording rate. Other data were recorded at their specified instrumental sample rates, which

are all less than 120 Hz. Data were converted to an ASCII format and imported into a Geosoft format database for processing. With the exception of the differential GPS post-processing, all data processing was conducted using the Geosoft software suite and proprietary ORNL algorithms and filters. The quality control, positioning, and magnetic data processing procedures (steps a-i) are described below.

Quality Control
All data were examined in the field to ensure sufficiently high quality for final processing. The adequacy of the compensation data, heading corrections, time lags, orientation calibration, overall performance and noise levels, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were reacquired. Data were also examined for high noise levels, data drop outs, significant diurnal activity, or other unacceptable conditions. Lines flown, but deemed to be unacceptable for quality reasons, were re-flown.

Positioning
During flight, the pilot was guided by an on-board navigation system that used real-time satellite-based DGPS positions. This provided sufficient accuracy for data collection (approximately 1m), but was inadequate for final data positioning. To increase the accuracy of the final data positioning, a base station GPS was established at Albuquerque International Sunport at ABQ-F (NAD83 35° 01’ 34.95330” N 106° 37’ 45.08087” W NAVD88 1620.10m), a first order geodetic survey marker. Raw data in the aircraft and on the ground were collected. Differential corrections were post-processed to provide increased accuracy in the final data positioning. The final latitude and longitude data were projected onto an orthogonal grid using the North American Datum 1983 (NAD 83) UTM Zone 13N. Vertical positioning was monitored by laser altimeter with an accuracy of 2cm. No filtering was required of these data, although occasional drop-outs were removed.

Magnetic data processing procedure
The magnetic data were subjected to several stages of geophysical processing. These stages included correction for time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. The calculation of the magnetic analytic signal was derived from the corrected residual magnetic total field data.

(a) Time Lag Correction
There is a lag between the time the sensor makes a measurement and when it is time stamped and recorded. This applies to both the magnetometer and the GPS. Accurate positioning requires a correction for this lag. Time lags between the 8 Cs-vapor magnetometers, fluxgate magnetometer, and GPS signals were measured with proprietary ORAGS firmware. This utility sends a single pulse that is visible in the data streams of all three instruments. This lag was corrected in all data streams before processing.

(b) Sensor Dropouts
Cesium vapor magnetometers have a preferred orientation to the Earth’s magnetic field. As a result of the motion of the aircraft, the sensor dead zones can occasionally align with the Earth’s

field. In this event, the readings drop out, usually from an average of 53,000 nT to 0 nT. This usually only occurs during turn-around between lines, and rarely during actual data acquisition. All dropouts were removed manually before processing.

(c) Aircraft Compensation
The presence of the helicopter in close proximity to the magnetic sensors results in considerable deviation in the readings, and generally requires some form of compensation. The orientation of the aircraft with respect to the sensors and the motion of the aircraft through the earth's magnetic field are also contributing factors. A special calibration flight is performed to record the information necessary to remove these effects. The maneuver consisted of a square or rectangular-shaped flight path at high altitude to gain information in each of the cardinal directions. During this procedure, the pitch, roll and yaw of the aircraft were varied. This provided a complete picture of the effects of the aircraft at all headings in all orientations. The entire maneuver was conducted twice for comparison. The information was used to calculate coefficients for a 19-term polynomial for each sensor. The fluxgate data were used as the baseline reference channel for orientation. The polynomial is applied post flight to the raw data, and the results are generally referred to as the compensated data. These data are used in the development of the analytic signal maps presented in this report.

(d) Magnetic Diurnal Variations
The earth's magnetic field changes constantly over the course of the day. This means that magnetic measurements include a randomly drifting background level. A base station sensor was established near the GPS base station monument at Albuquerque International Sunport to monitor and record this variation every five seconds. The recorded data are normally subtracted directly from the airborne data. The time stamps on the airborne and ground units were synchronized to GPS time. The diurnal activity recorded at the base station was extremely quiet. In general, the low frequency diurnal variations were less than 5nT per survey line. Processing included defaulting repeated values and linearly interpolating between the remaining points.

(e) Heading Corrections
Cesium vapor magnetometers are susceptible to heading errors. The result is that one sensor will give different readings when rotated about a stationary point. This error is usually less than 0.2 nT. Heading corrections were applied to adjust readings for this effect.

(f) Array Balancing
These magnetic sensors also provide a lower degree of absolute accuracy than relative accuracy. Different sensors in identical situations will measure the same relative change of 1 nT, but they may differ in their actual measured value, such as whether the change was from 50,000 to 50,001 nT or from 50,100 to 50,101 nT. After individual sensors were heading-corrected to a uniform background reading, the background level of each sensor was corrected or balanced to match the others across the entire airborne array.

(g) Regional Removal
Deep-seated, large scale background geology and some cultural features which contribute to the local regional magnetic field were removed using a combination of filtering and splining

techniques. The output is a residual magnetic total field. This process also removed all diurnal, heading and balancing effects.

(h) Rotor Noise
The aircraft rotor spins at a constant rate of approximately 400 rpm. This introduces noise to the magnetic readings at a frequency of approximately 6.6 Hz. Harmonics at multiples of this base are also observable, but are much smaller. This frequency is usually higher than the spatial frequency created by near surface metallic objects. This effect has been removed with a low-pass frequency filter.

(i) Analytic Signal
The data resulting from this survey are presented in the form of analytic signal (the square root of the sum of the squares of the three orthogonal magnetic gradients is the total gradient or analytic signal). It represents the maximum rate of change of the magnetic field in any direction. This parameter was calculated from the gridded residual total magnetic field data.

3.6.7 Sampling Plan

This section does not apply to this report.

3.6.8 Demobilization

De-installation was carried out on February 27, 2003. Booms were dismounted from the helicopter frame and the magnetometers and GPS instrumentation were disconnected and packed in shipping containers. The containers were placed in a trailer for transport to ORNL. The helicopter crew demobilized and departed for Ontario on February 27. The ground and air crews arrived at their respective bases on February 29.

4.0 Performance Assessment

4.1 Performance Criteria

Demonstration effectiveness is determined directly from comparisons of the processed/analyzed results from the demonstration surveys and the results of previous airborne and ground-based surveys. These comparisons include both the quantitative and qualitative items described in this section. Demonstration success is determined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in this document (Section 3.1). Methods utilized by ORNL on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters (e.g. GPS, magnetometer operation, data recording, system compensation measurements, etc.) in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Altitude can be recorded and is entered into the data analysis and comparisons with previous results. The aircraft attitude measuring system provides a documented database that cannot be directly compared with previous surveys when this system was not available. The consistent and scientific evaluation of performance is accomplished by using identical or parallel (where parameters are dataset dependent) processing methods with identical software to produce a final map, and following consistent procedures in interpretation when comparing new and existing datasets from the test sites.

Data processing involves several steps, including GPS post-processing, compensation, spike removal, removal of magnetic diurnal variations, time lag correction, heading correction, filtering, gradient calculations, and gridding. Each step is performed in the same manner on data acquired with sequential generations of system at the same sites, to provide a basis for comparing the performance of the systems. The processing procedures have been selected and developed from experience with similar data over a span of more than five years for optimal sensitivity to UXO.

Data quality objectives, as described in Section 3.6.6 (Experimental Design), were used for this demonstration. Surveys over the previously described test areas were conducted as described in Section 3.6. Data collection occurred at flight altitudes over the various test areas and configurations as described in Section 3.6.6. Data confirmation was in accordance with the processes previously described in this section.

Table 4.1 identifies the expected performance criteria for this demonstration, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative). This table also identifies expected performance for each of the technologies present in this demonstration.

Table 4.1: Performance Criteria

Performance Criteria	Expected Performance Metric (Pre-demo)	Performance Confirmation Method	Actual Performance (Post-demo)
Primary Criteria (Performance Objectives) – Quantitative			
System Performance (total field system)	Ordnance detection – greater than 90%	Comparison of dig lists to excavation results	Non-seed 78% Seed 46% Ave 70%
System Performance (total field system)	False positives – less than or equal to 6%	Comparison of dig lists to excavation results.	14% of total excavations were clutter
System Performance (total field system)	Data acquisition rate – greater than or equal to 40 acres per hour	Measurement of acres flown vs time required	96 acres/hour, including turnaround time
System Performance (total field system)	Detection threshold (sensitivity)	Determination of minimum anomaly threshold	~5 nT for reliable detection
System Performance (total field system)	Anomaly positional accuracy	Comparison of dig locations to excavation results	Avg 103cm Std dev 45cm At 2m search radius
Factors Affecting Technology	Helicopter geophysical noise	Comparison of sensor compensation measurements against prior compensation values	FOM for sensors 3&6 reduced from 8.1 to 2.9nT.
Primary Criteria (Performance Objectives) – Qualitative			
Process Waste	None	Observations	No process waste.
Secondary Criteria (Performance Objectives) – Quantitative			
Hazardous	None expected, other than spotting charges	Observations and documentation during excavations	All UXO-related

Materials	in M38 practice ordnance		materials excavated were labeled UXO-fragments
Secondary Criteria (Performance Objectives) – Qualitative			
Reliability	No system or component failures	Observations and documentation	No components failed during the total field surveys
Ease of Use	Pilot "comfort" when flying with the system installed	Observations and documentation	Pilot states that he feels at ease flying the system under normal wind conditions
Ease of Use	No ballast required	Observations and documentation	Engineer declared the system balanced without need for ballast
Safety	Conformance with all FAA requirements and requirements as documented in the Mission Plan	Observations and documentation	System met all FAA flightworthiness requirements
Versatility	Cultural feature detection and mapping	Comparison of anomaly count, strength, and position to previously collected MTADS data at PBR N-9 and N-10 regarding barbwire fence crossing the middle of the targets	Fence clearly discernable from ordnance targets.
Maintenance	System mount points, hardware, and component inspection	Observations and documentation	Minimal wear and tear.

4.2 Performance Confirmation Methods

Accurate estimation of two of the system performance criteria, i.e. ordnance detection and false positives, are dependent largely on the method of post-survey excavation used. For the Pueblo of Isleta survey, 433 excavations were made, all based on airborne- and ground-MTADS anomalies in area S-01 and were combined with 112 seeded items. For this project, frag items were classified as ordnance by IDA for the purposes of declaring a successful hit since they were largely M38 body parts. Due primarily to the inherent limitations of the orientation measurement system, target accuracies required a 2m search radius to maximize detection capabilities. All analysis shown here is based on this search radius, although data for 1.5m and 1.0m radii are also provided.

4.3 Data Analysis, Interpretation, and Evaluation

The ORAGS-Arrowhead magnetometer system does not distinguish among the numerous features mapped between UXO and ferrous scrap without interpretation. The total field and analytic signal maps provided in this report depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of ferrous debris associated with human activity), and potential UXO items (discrete sources). Those responses, interpreted as potential UXO, will likely also include smaller pieces of ferrous debris. Additional analysis and interpretation of the survey results are included in this final project report.

Positional accuracy

We calculated positional accuracy by comparison of predicted dig locations with actual dig results provided by ESTCP. Complete excavation results are provided in Appendix E. The mean distance between the ORAGS predicted ordnance position and the actual record ordnance location was 103cm with a standard deviation of 45cm.

Sensitivity

In the south central portion of site S-01, where the vast majority of digs were conducted, the practical limit at which the ORAGS-Arrowhead system was able to clearly map dipolar anomalies was at peak-to-peak total field anomaly amplitude of about 5.5 nT. Below about 5 nT, magnetic anomalies did not exhibit a clear dipolar signature, presumably because ground clutter or magnetic background from soil or bedrock were superimposed on these small anomalies.

Site S-01

Site S-01 is a 2.2 km (E-W) x 3.0 km (N-S) rectangular area comprising about 660 ha centered over a bombing target. Most of the area is topographically flat with low vegetation, and thus well-suited for low-flying helicopter surveys (Figure 4.1). Rougher topography and higher vegetation on the eastern side of the area necessitated higher-than-usual survey altitudes (over 5 m, Figure 4.3) over about 20% of the site. Lines were flown in a north-south direction, and completely covered the target with a 12m flight line separation. Surface fragments indicated that the most likely type of ordnance to be encountered were M-38 practice bombs, although larger bombs were also evident (Figure 4.2). A semicircular anomaly in the western portion of the surveyed area is a berm that marked the bombing target. In the east, a fence runs roughly north-south. Figures 4.4 and 4.5 show anomaly maps of the total magnetic field and analytic signal for a nominal 2 m survey height. Figure 4.6 shows profile data fore line 10530.4 across the center of the S-01 target. The average along line survey speed in S-01 was about 15 m/s, although the speed was as low as 7 m/s in areas where the pilot was forced to avoid sparse trees but maintain a sufficiently low flight height, and over 25 m/s in areas where no obstacles were present. The average coverage rate was 39 ha/hr (96 acres/hr).

Figure 4.1 View of site S-01, Pueblo of Isleta, New Mexico.

Figure 4.2 Partially buried 500 pound bomb on outskirts of site S-01.

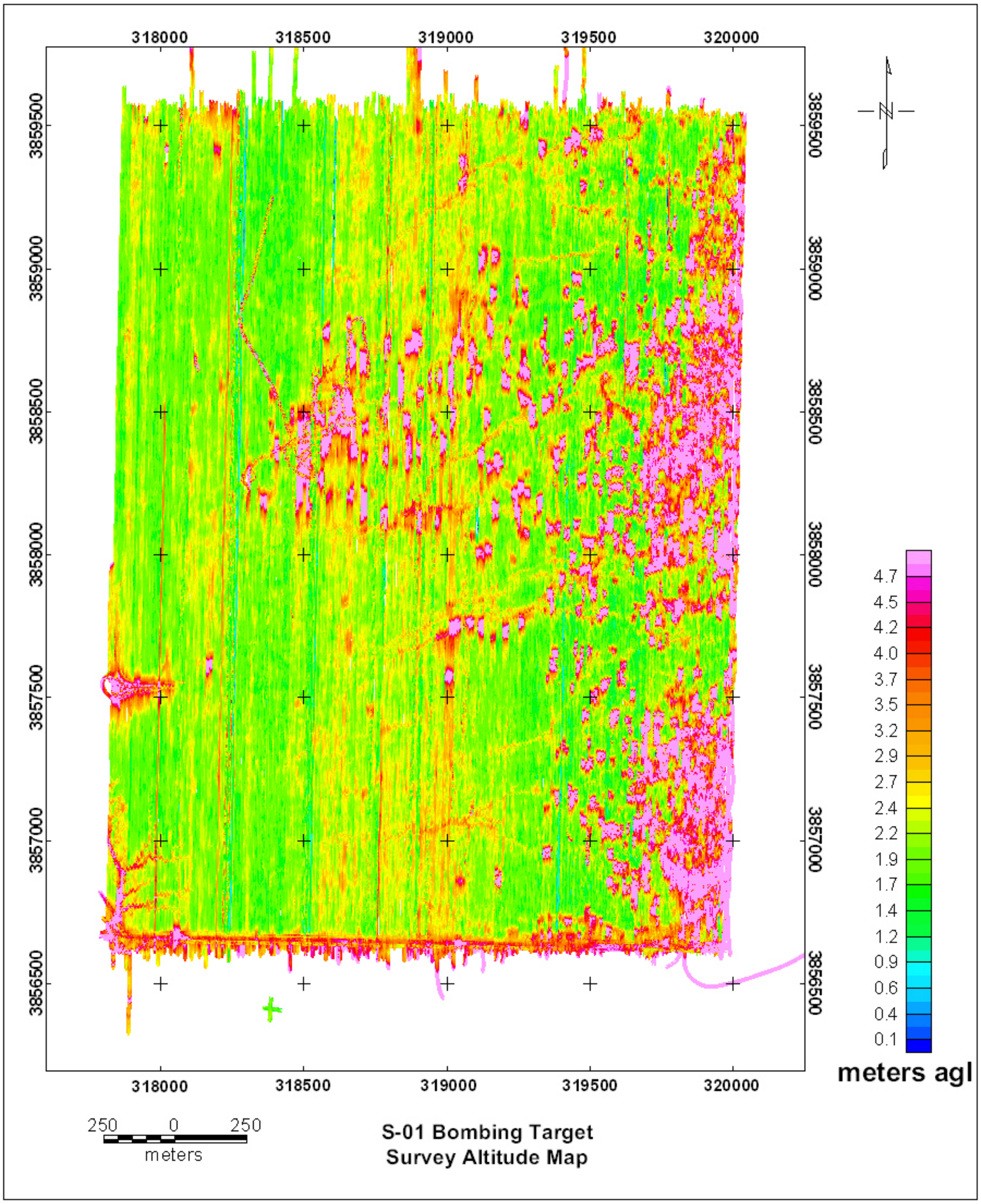

Figure 4.3 Map of ORAGS-Arrowhead S-01 survey altitude above ground level.

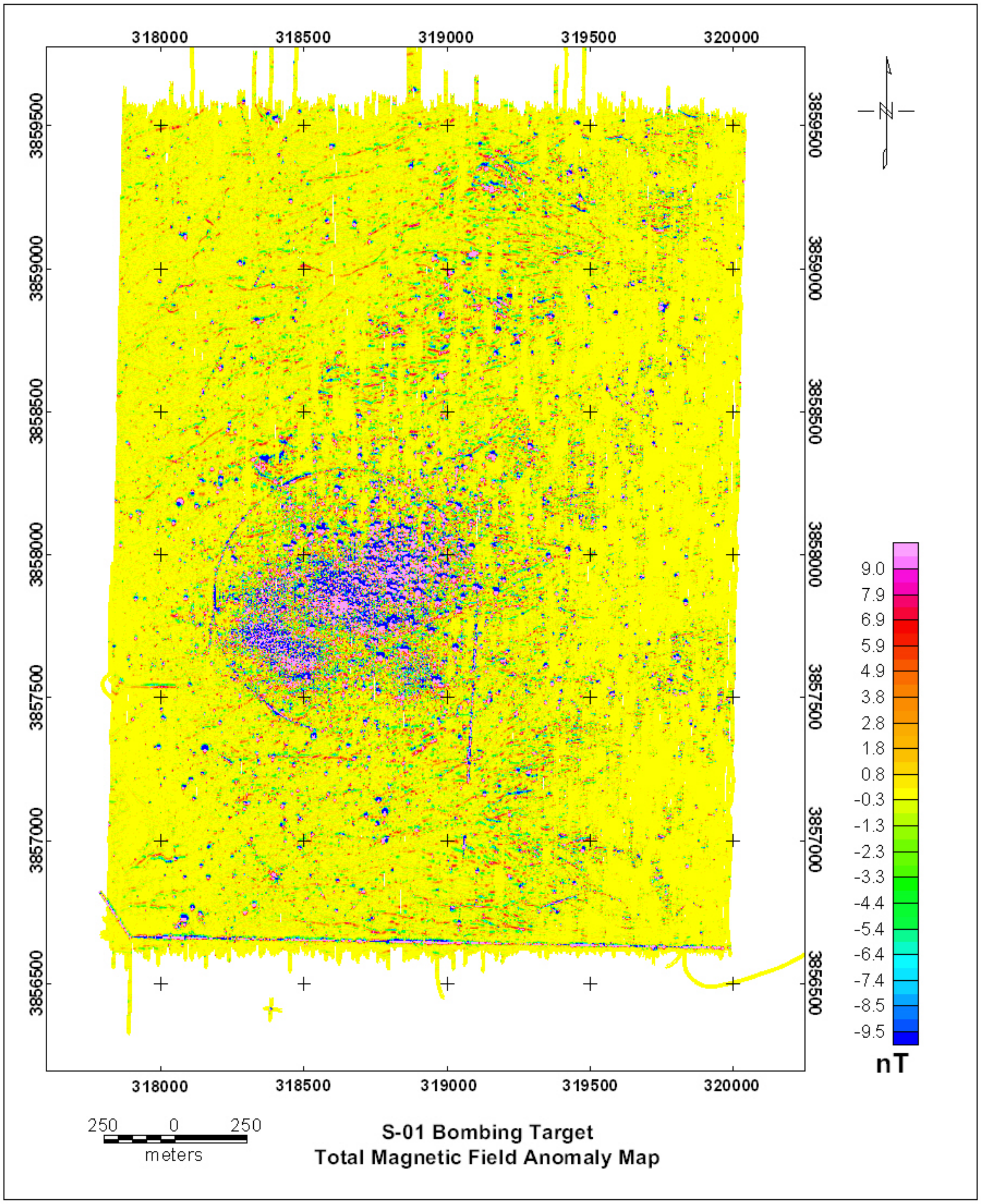

Figure 4.4 Total magnetic field residual anomaly map, site S-01 for a nominal 2m survey height.

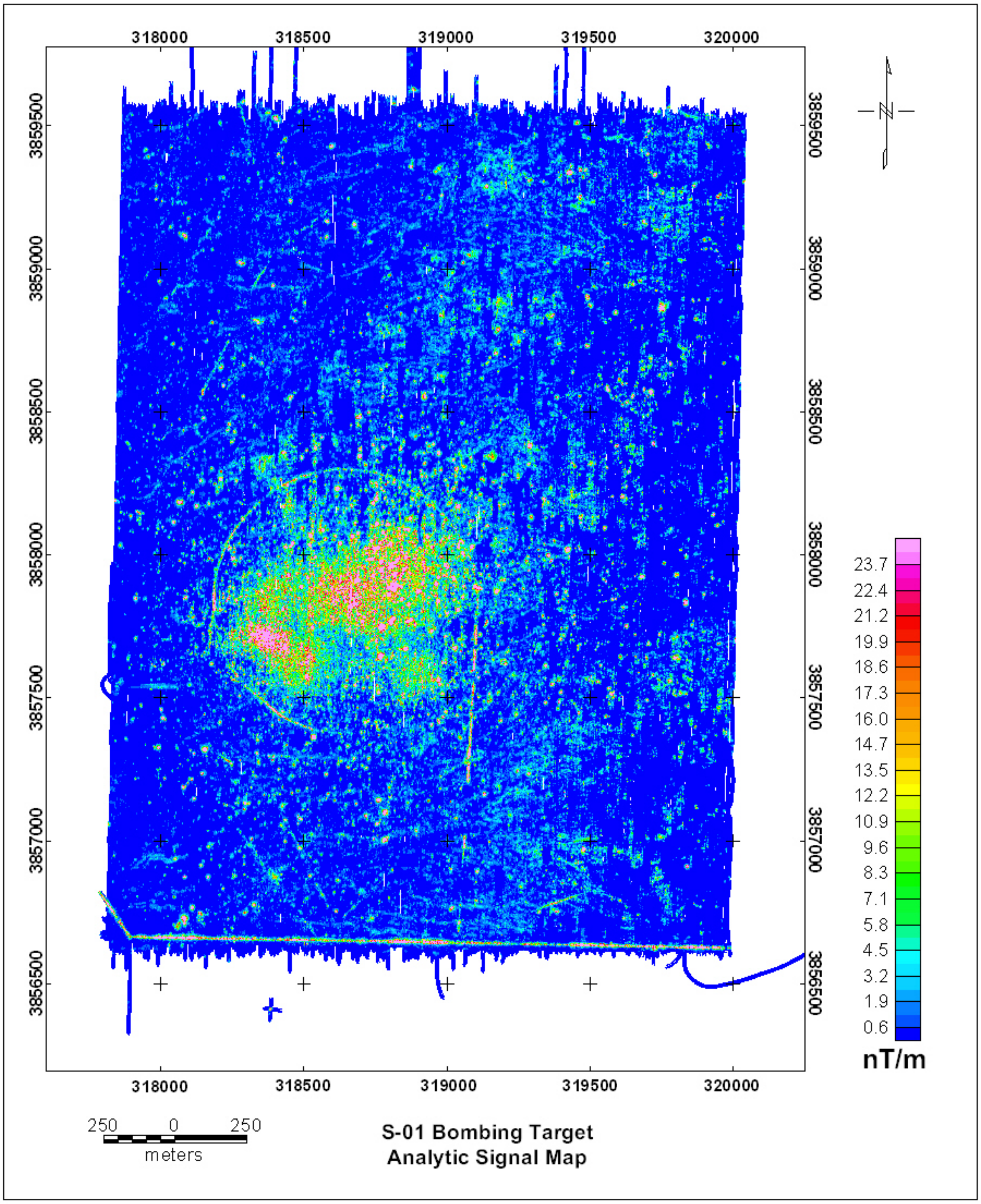

Figure 4.5 Analytic signal anomaly map, site S-01, for a nominal 2m survey height.

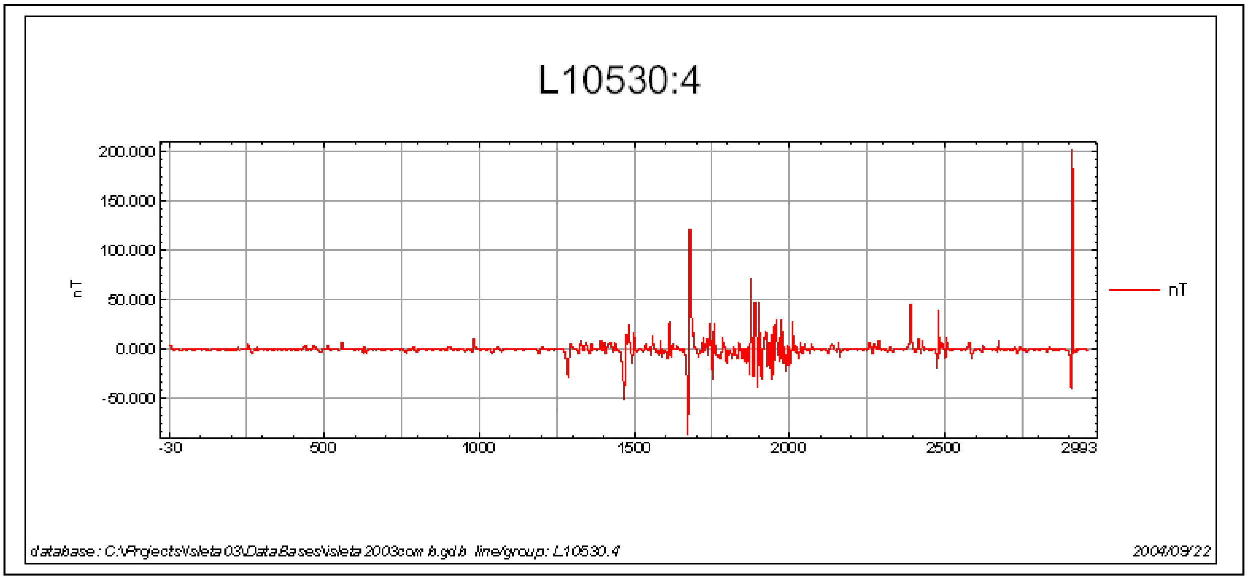

Figure 4.6 Three kilometer south to north total field data profile of line over center of target S-01. Horizontal axis in meters.

Sensor noise levels

Sensors behaved as expected during the demonstration, and sensor noise levels were at or below levels measured in previous demonstration surveys. Figure 4.7 shows raw total magnetic field data high passed at 20 fiducials for 45 second section of line 11050 at site S-01. The separate sensor responses have been offset to better display them together. Figure 4.8 shows the noise from each sensor as one standard deviation for the lines of data shown in Figure 4.7. Clearly, the inboard port sensor on the rear boom is the noisiest, at 1.85 nT. The reason for the high noise level could be a loose connection of the magnetometer assembly to the boom, or simply a poorly performing magnetometer. The average noise level of all eight magnetometers is 0.9 nT.

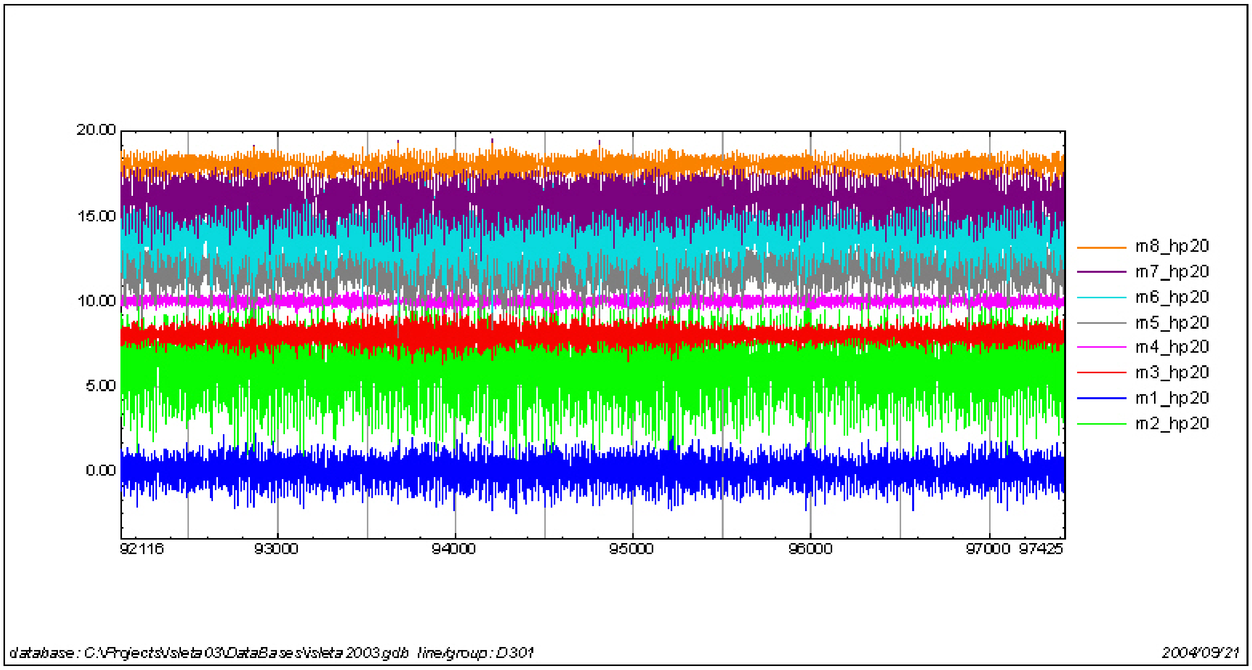

Figure 4.7 Noise on all eight sensors, as shown in high pass filter with a cut off of 20 fiducials (~4 m or 0.2 s) from raw total magnetic field. Signals are offset for better presentation. Horizontal axis in fiducials (downsampled rate: 120 fids/s).

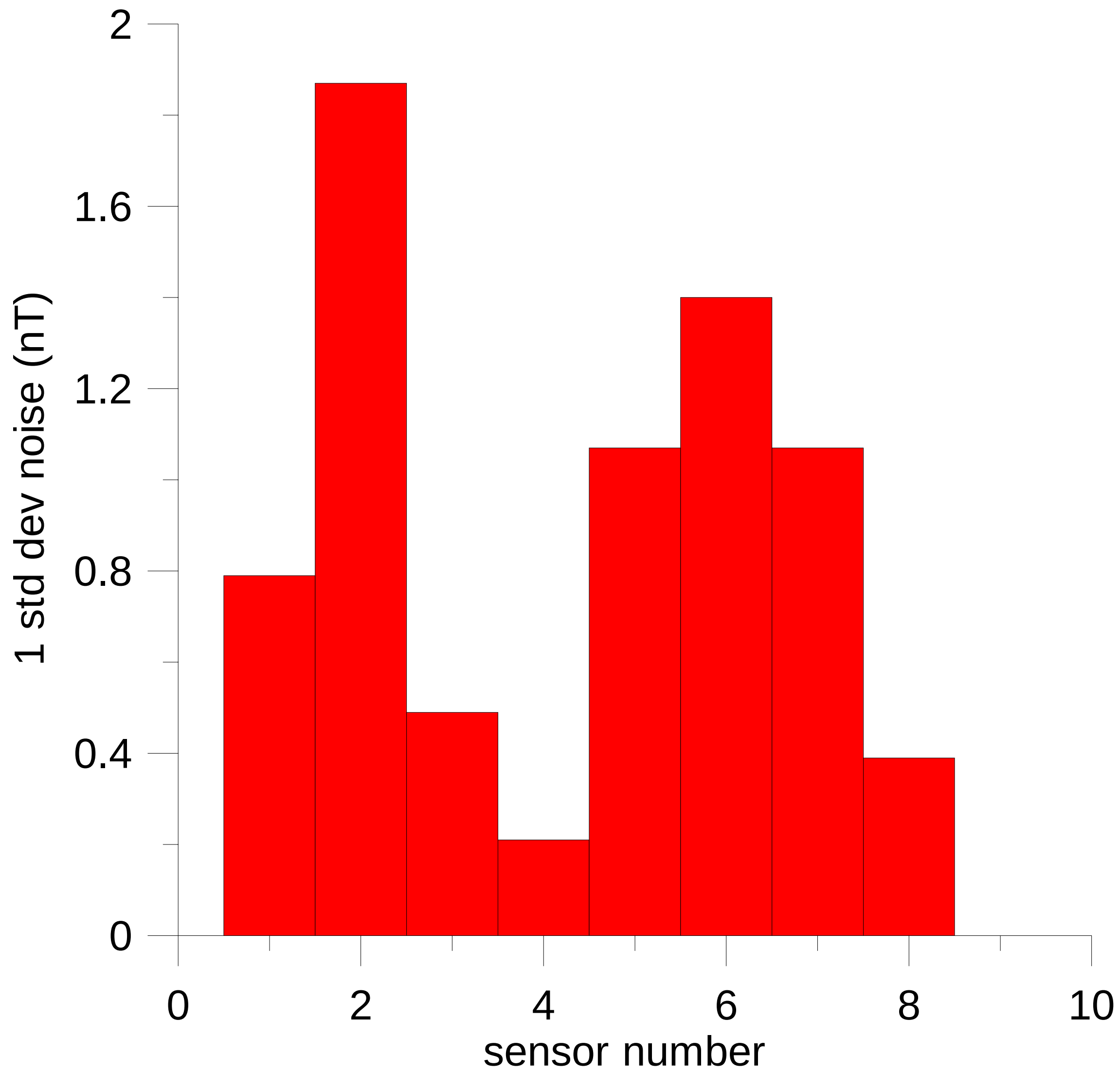

Figure 4.8 Comparative low altitude peak-to-peak RMS noise levels of sensors 1-8 along line 1010 in S-01. Sensors 2, the inboard sensors on the port side rear boom, has a noticeably higher noise level than the other six sensors. Note that noise levels on any given sensor may vary with flight direction.

Anomaly evaluation overview

Evaluation of anomalies used ground- and airborne-MTADS (aMTADS) dig results from site S-01. All validation was conducted under the direction of the Naval Research Laboratory (NRL). Digs were carried out under NRL subcontract by Explosive Ordnance Technologies, Inc. of Rumson, New Jersey. Anomalies were placed into one of six categories according to semblance to UXO: 1 (definitely UXO), 2 (probable UXO), 3 (possible UXO), 4 (possible scrap), 5 (probable scrap), 6 (definitely scrap).

Two different data processing techniques were applied to this site, and both were interpreted separately. The first is the standard processing approach using the techniques and filters described in section 3.6.6. As mentioned previously, the results quoted here assume a 2m search radius to reflect the reduced positioning accuracy caused by the inadequate orientation system. The second approach presented used a new Hum filter to remove rotor noise. This technique proved to produce numerous artifacts which increase the number of false alarms.

Results from Standard interpretation

Results of the ORNL system performance using data that were not hum filtered are summarized in tables 4.2 through 4.7. For analysis purposes, the site was divided into two sections. The first was surveyed by all three geophysical techniques (ORAGS, airborne MTADS and ground MTADS). The second was surveyed only by air. Targets were classified as either seed items or non-seed items (selected by ESTCP from the dig list). The anomaly source at each excavation site was categorized by type into ordnance and clutter. The detection percentage is calculated as the number of items found over the total number excavated. It should be noted that not all detected anomalies were excavated, so there is no way to measure a false negative response, and the detection probabilities quoted here are only approximations.

As with the APG results (ORNL 2004b) the ordnance detection performance on non-seed excavations (double-blind test, 78%) was significantly better that of the seeded items (blind test, 46%). As with the APG results, this implies that the seed items do not necessarily reflect true ordnance signatures at this site. Combining both of these sets of items produces an average detection probability of 70%. Rough terrain, high speeds (up to 25 m/s) and higher flight altitude are contributing factors to the low detection rate.

The statistical classifier used to prioritize the dig list needs improvement. As seen in Tables 4.2 to 4.7 the average priority of the ordnance items was about 4.5, indicating non-UXO. Ironically, the clutter had a higher average priority of about 3.8. The lack of a robust training set for the classifier is a problem, and the ordnance items found at Isleta were different than those initially used to calibrate the statistical classifier. Ideally, we would like to distinguish exploded UXO fragments from intact UXO to expedite any subsequent cleanup action. The rich data sets from Isleta and APG will be used for a recalibration of the statistical classifier.

More detailed results from the Isleta excavations can be found in Appendix E:

Table 4.2: Detection results for 2.0m search radius.

Type	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	308	442	70%	4.5	1.03	0.45	70%
Ordnance -dig only	257	330	78%	4.5	1.01	0.44	
Ordnance -seed only	51	112	46%	4.2	1.12	0.46	
Clutter	75	103	73%	3.8	1.07	0.40	14%

Table 4.3: Detection results for 1.5m search radius.

Type	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	257	442	58%	4.4	0.89	0.35	58%
Ordnance -dig only	218	330	66%	4.4	0.88	0.34	
Ordnance -seed only	39	112	35%	4.1	0.93	0.36	
Clutter	64	103	62%	3.6	0.95	0.30	12%

Table 4.4: Detection results for 1.0m search radius.

Type	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	155	442	35%	4.4	0.66	0.22	35%
Ordnance -dig only	136	330	41%	4.5	0.66	0.22	
Ordnance -seed only	19	112	17%	3.7	0.62	0.22	
Clutter	33	103	32%	3.7	0.72	0.22	6%

Table 4.5: Expanded detection results for 2.0m search radius.

Area	Class	Type	Item	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	28	39	72%	3.8	1.07	0.43
3sys	dig	Clutter	Scrap	35	49	71%	3.4	0.97	0.36
3sys	dig	Ordnance	Frag	56	65	86%	2.9	0.98	0.43
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	5.0	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	1	1	100%	3.0	0.24	0.00
3sys	dig	Ordnance	BDU	1	1	100%	4.0	1.83	0.00
3sys	dig	Ordnance	Missile Comp	1	1	100%	4.0	1.20	0.00
3sys	dig	Ordnance	MK-76	4	4	100%	3.8	1.05	0.56
Air	dig	Clutter	Geology	3	4	75%	5.3	1.33	0.24
Air	dig	Clutter	Scrap	9	11	82%	4.8	1.32	0.41
Air	dig	Ordnance	Frag	146	191	76%	5.0	1.04	0.45
Air	dig	Ordnance	1000lb Bomb	2	2	100%	4.0	1.01	0.13
Air	dig	Ordnance	500lb Bomb	6	8	75%	5.0	0.91	0.54
Air	dig	Ordnance	Burster Cup	0	1	0%	0.0	0.00	0.00
Air	dig	Ordnance	M38	3	4	75%	4.3	0.92	0.53
Air	dig	Ordnance	Missile w/h	1	1	100%	6.0	1.05	0.00
Air	dig	Ordnance	MK-23	1	1	100%	6.0	0.69	0.00
Air	dig	Ordnance	MK-76	29	43	67%	5.1	0.95	0.42
Air	dig	Ordnance	MK-81	1	1	100%	6.0	1.53	0.00
Air	dig	Ordnance	MK-83	1	1	100%	4.0	0.73	0.00
Air	dig	Ordnance	Nuclear SIM	3	4	75%	5.3	1.16	0.45
Air	seed	Ordnance	105mm	22	40	55%	4.0	1.12	0.46

Air	seed	Ordnance	2.75in	8	12	67%	3.0	0.95	0.64
Air	seed	Ordnance	60mm	6	20	30%	5.2	1.20	0.43
Air	seed	Ordnance	81mm	15	40	38%	4.9	1.17	0.38

Table 4.6: Expanded detection results for 1.5m search radius.

Area	Class	Type	Item	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	24	39	62%	3.7	0.96	0.35
3sys	dig	Clutter	Scrap	33	49	67%	3.3	0.92	0.28
3sys	dig	Ordnance	Frag	50	65	77%	2.8	0.90	0.36
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	5.0	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	1	1	100%	3.0	0.24	0.00
3sys	dig	Ordnance	BDU	0	1	0%	0.0	0.00	0.00
3sys	dig	Ordnance	Missile Comp	1	1	100%	4.0	1.20	0.00
3sys	dig	Ordnance	MK-76	3	4	75%	4.0	0.81	0.36
Air	dig	Clutter	Geology	2	4	50%	5.5	1.22	0.23
Air	dig	Clutter	Scrap	5	11	45%	4.6	1.02	0.22
Air	dig	Ordnance	Frag	120	191	63%	4.9	0.89	0.34
Air	dig	Ordnance	1000lb Bomb	2	2	100%	4.0	1.01	0.13
Air	dig	Ordnance	500lb Bomb	5	8	63%	5.4	0.70	0.20
Air	dig	Ordnance	Burster Cup	0	1	0%	0.0	0.00	0.00
Air	dig	Ordnance	M38	3	4	75%	4.3	0.92	0.53
Air	dig	Ordnance	Missile w/h	1	1	100%	6.0	1.05	0.00
Air	dig	Ordnance	MK-23	1	1	100%	6.0	0.69	0.00
Air	dig	Ordnance	MK-76	27	43	63%	5.0	0.88	0.35
Air	dig	Ordnance	MK-81	0	1	0%	0.0	0.00	0.00
Air	dig	Ordnance	MK-83	1	1	100%	4.0	0.73	0.00
Air	dig	Ordnance	Nuclear SIM	2	4	50%	5.0	0.97	0.44
Air	seed	Ordnance	105mm	16	40	40%	3.7	0.90	0.33
Air	seed	Ordnance	2.75in	6	12	50%	3.2	0.67	0.45
Air	seed	Ordnance	60mm	5	20	25%	5.0	1.07	0.32
Air	seed	Ordnance	81mm	12	40	30%	4.8	1.05	0.34

Table 4.7: Expanded detection results for 1.0m search radius.

Area	Class	Type	Item	Found	Total	Rate	Avg Priority	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	10	39	26%	3.7	0.63	0.26
3sys	dig	Clutter	Scrap	21	49	43%	3.5	0.75	0.20
3sys	dig	Ordnance	Frag	30	65	46%	2.8	0.66	0.24
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	5.0	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	1	1	100%	3.0	0.24	0.00
3sys	dig	Ordnance	BDU	0	1	0%	0.0	0.00	0.00
3sys	dig	Ordnance	Missile Comp	0	1	0%	0.0	0.00	0.00
3sys	dig	Ordnance	MK-76	2	4	50%	5.0	0.60	0.02
Air	dig	Clutter	Geology	0	4	0%	0.0	0.00	0.00
Air	dig	Clutter	Scrap	2	11	18%	5.5	0.81	0.20
Air	dig	Ordnance	Frag	73	191	38%	4.9	0.67	0.23
Air	dig	Ordnance	1000lb Bomb	1	2	50%	5.0	0.92	0.00
Air	dig	Ordnance	500lb Bomb	4	8	50%	5.5	0.62	0.12
Air	dig	Ordnance	Burster Cup	0	1	0%	0.0	0.00	0.00

Air	dig	Ordnance	M38	2	4	50%	4.0	0.65	0.34
Air	dig	Ordnance	Missile w/h	0	1	0%	0.0	0.00	0.00
Air	dig	Ordnance	MK-23	1	1	100%	6.0	0.69	0.00
Air	dig	Ordnance	MK-76	19	43	44%	4.9	0.69	0.22
Air	dig	Ordnance	MK-81	0	1	0%	0.0	0.00	0.00
Air	dig	Ordnance	MK-83	1	1	100%	4.0	0.73	0.00
Air	dig	Ordnance	Nuclear SIM	1	4	25%	6.0	0.66	0.00
Air	seed	Ordnance	105mm	10	40	25%	3.6	0.68	0.17
Air	seed	Ordnance	2.75in	4	12	33%	3.3	0.43	0.31
Air	seed	Ordnance	60mm	1	20	5%	5.0	0.58	0.00
Air	seed	Ordnance	81mm	4	40	10%	4.3	0.64	0.20

Hum Filter Application

An experimental hum filter (Xia, 2002) was originally applied to the entire data set. Anomaly locations provided to IDA were from the hum filtered data. Although the Hum filter proved beneficial on small data sets it proved to be unstable when applied to the S-01 data set causing data artifacts and positional errors. Testing of this was conducted after data deliverable had been given to IDA. To make a more accurate assessment of system performance as compared to other sites the results were reanalyzed using standard filtering and picking procedures as reported above. The effect of the Hum filter is explained in more detail in the Self Assessment report to ESTCP (ORNL 2004c).

Excavation results for the Hum filtered data are summarized in Tables 4.8 to 4.13. As with the standard data processing, the detection of seeded items (blind-test) was considerably less than the detection of the non-seed items (double-blind). The average detection rate was 67% with a 24% false positive rate at a 2m search radius. This was a marginally poorer detection rate than the results from the standard data set. The positioning errors for this data set were almost double the standard approach, having an average 190cm error with a standard deviation of 84cm.

The false positive rate was also substantially higher for the Hum filtered data (24%) than the standard processing (14%). This value is also high in comparison to other surveys where more standard field excavation techniques were used (for example, <3% at BBR, Van et al., 2004). The reasons for this high percentage of no finds are not entirely clear, but a number of factors can be identified as probable contributors. The major contributor to the poor performance results was the data artifacts caused by the application of the hum filter. Secondly, this number is artificially high in part because excavation radii did not extend beyond 1m. Because the ORAGS-Arrowhead system's average positioning error for this survey was at or near 1m, the narrow search/dig radius would have artificially inflated the number of no finds, since about half the targets would fall outside a 1m dig radius.

Table 4.8: Detection results from hum filtered data for 2.0m search radius.

Type	Found	Total	Rate	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	168	251	67%	1.90	0.84	67%
Ordnance -dig only	255	330	77%	0.99	0.45	
Ordnance -seed only	55	112	49%	1.20	0.47	
Clutter	84	103	82%	0.99	0.42	24%

Table 4.9: Detection results from hum filtered data for 1.5m search radius.

Type	Found	Total	Rate	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	135	251	54%	1.65	0.66	54%
Ordnance -dig only	218	330	66%	0.86	0.35	
Ordnance -seed only	37	112	33%	0.94	0.32	
Clutter	72	103	70%	0.87	0.33	20%

Table 4.10: Detection results from hum filtered data for 1.0m search radius.

Type	Found	Total	Rate	Pos Error	Error Stdev	Avg Pd, FP
Ordnance -all	77	251	31%	1.26	0.43	31%
Ordnance -dig only	136	330	41%	0.64	0.22	
Ordnance -seed only	17	112	15%	0.63	0.19	
Clutter	45	103	44%	0.66	0.21	13%

Table 4.11: Expanded detection results from hum filtered data for 2.0m search radius.

Area	Class	Type	Item	Found	Total	Rate	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	35	39	90%	0.93	0.43
3sys	dig	Clutter	Scrap	37	49	76%	0.96	0.43
3sys	dig	Ordnance	Frag	59	65	91%	0.98	0.45
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	1	1	100%	1.62	0.00
3sys	dig	Ordnance	BDU	0	1	0%	0.00	0.00
3sys	dig	Ordnance	Missile Comp	1	1	100%	1.20	0.00
3sys	dig	Ordnance	MK-76	2	4	50%	0.99	0.52
Air	dig	Clutter	Geology	4	4	100%	1.36	0.21
Air	dig	Clutter	Scrap	8	11	73%	1.22	0.48
Air	dig	Ordnance	Frag	142	191	74%	1.00	0.47
Air	dig	Ordnance	1000lb Bomb	2	2	100%	1.01	0.13
Air	dig	Ordnance	500lb Bomb	7	8	88%	0.95	0.49
Air	dig	Ordnance	Burster Cup	0	1	0%	0.00	0.00
Air	dig	Ordnance	M38	3	4	75%	0.92	0.53
Air	dig	Ordnance	Missile w/h	1	1	100%	1.17	0.00
Air	dig	Ordnance	MK-23	1	1	100%	0.83	0.00
Air	dig	Ordnance	MK-76	30	43	70%	0.92	0.45
Air	dig	Ordnance	MK-81	1	1	100%	1.53	0.00
Air	dig	Ordnance	MK-83	1	1	100%	1.21	0.00
Air	dig	Ordnance	Nuclear SIM	3	4	75%	1.26	0.57
Air	seed	Ordnance	105mm	21	40	53%	1.24	0.47
Air	seed	Ordnance	2.75in	10	12	83%	1.11	0.58
Air	seed	Ordnance	60mm	6	20	30%	1.36	0.33
Air	seed	Ordnance	81mm	18	40	45%	1.15	0.45

Table 4.12: Expanded detection results from hum filtered data for 1.5m search radius.

Area	Class	Type	Item	Found	Total	Rate	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	31	39	79%	0.82	0.33
3sys	dig	Clutter	Scrap	33	49	67%	0.87	0.34
3sys	dig	Ordnance	Frag	51	65	78%	0.87	0.38
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	0	1	0%	0.00	0.00
3sys	dig	Ordnance	BDU	0	1	0%	0.00	0.00
3sys	dig	Ordnance	Missile Comp	1	1	100%	1.20	0.00
3sys	dig	Ordnance	MK-76	2	4	50%	0.99	0.52
Air	dig	Clutter	Geology	3	4	75%	1.31	0.22

Air	dig	Clutter	Scrap	5	11	45%	0.92	0.31
Air	dig	Ordnance	Frag	120	191	63%	0.86	0.36
Air	dig	Ordnance	1000lb Bomb	2	2	100%	1.01	0.13
Air	dig	Ordnance	500lb Bomb	6	8	75%	0.78	0.24
Air	dig	Ordnance	Burster Cup	0	1	0%	0.00	0.00
Air	dig	Ordnance	M38	3	4	75%	0.92	0.53
Air	dig	Ordnance	Missile w/h	1	1	100%	1.17	0.00
Air	dig	Ordnance	MK-23	1	1	100%	0.83	0.00
Air	dig	Ordnance	MK-76	27	43	63%	0.83	0.37
Air	dig	Ordnance	MK-81	0	1	0%	0.00	0.00
Air	dig	Ordnance	MK-83	1	1	100%	1.21	0.00
Air	dig	Ordnance	Nuclear SIM	2	4	50%	0.98	0.43
Air	seed	Ordnance	105mm	13	40	33%	0.93	0.31
Air	seed	Ordnance	2.75in	7	12	58%	0.84	0.44
Air	seed	Ordnance	60mm	4	20	20%	1.15	0.10
Air	seed	Ordnance	81mm	13	40	33%	0.94	0.33

Table 4.13: Expanded detection results from hum filtered data for 1.0m search radius.

Area	Class	Type	Item	Found	Total	Rate	Pos Error	Error Stdev
3sys	dig	Clutter	Geology	21	39	54%	0.64	0.20
3sys	dig	Clutter	Scrap	21	49	43%	0.67	0.23
3sys	dig	Ordnance	Frag	28	65	43%	0.59	0.25
3sys	dig	Ordnance	1000lb Bomb	1	1	100%	0.59	0.00
3sys	dig	Ordnance	500lb Bomb	0	1	0%	0.00	0.00
3sys	dig	Ordnance	BDU	0	1	0%	0.00	0.00
3sys	dig	Ordnance	Missile Comp	0	1	0%	0.00	0.00
3sys	dig	Ordnance	MK-76	1	4	25%	0.62	0.00
Air	dig	Clutter	Geology	0	4	0%	0.00	0.00
Air	dig	Clutter	Scrap	3	11	27%	0.74	0.27
Air	dig	Ordnance	Frag	76	191	40%	0.64	0.23
Air	dig	Ordnance	1000lb Bomb	1	2	50%	0.92	0.00
Air	dig	Ordnance	500lb Bomb	5	8	63%	0.71	0.17
Air	dig	Ordnance	Burster Cup	0	1	0%	0.00	0.00
Air	dig	Ordnance	M38	2	4	50%	0.65	0.34
Air	dig	Ordnance	Missile w/h	0	1	0%	0.00	0.00
Air	dig	Ordnance	MK-23	1	1	100%	0.83	0.00
Air	dig	Ordnance	MK-76	20	43	47%	0.66	0.23
Air	dig	Ordnance	MK-81	0	1	0%	0.00	0.00
Air	dig	Ordnance	MK-83	0	1	0%	0.00	0.00
Air	dig	Ordnance	Nuclear SIM	1	4	25%	0.68	0.00
Air	seed	Ordnance	105mm	7	40	18%	0.70	0.19
Air	seed	Ordnance	2.75in	4	12	33%	0.53	0.25
Air	seed	Ordnance	60mm	6	20	30%	0.62	0.15
Air	seed	Ordnance	81mm	0	40	0%	0.00	0.00

4.4 Technical Conclusions

The ORAGS-Arrowhead total field magnetometry system provided data adequate for defining target zones in test ranges having areas on the order of hundreds of hectares. The total field data were sufficiently precise that positions of individual pieces of UXO and scrap could be identified to within a radius of 1 meter. Once on site, the ORAGS-Arrowhead system was able to collect data at a rate of about 100 acres per hour, a figure that includes turn-around time at the ends of lines. Peak-to-peak noise levels in the raw magnetic data were at or less than 1 nT in 6 of 8 sensors. In sensors 2 and 6 (the port inboard sensor of the rear boom and the outer starboard forward sensor), noise levels were in the range of 1-2 nT. Once filters were applied to noise induced by the blades and rotor, noise levels were reduced to ~0.2 nT or less in all sensors. Overall the system performance was less than previous surveys with an average detection rate of 70%.

5.0 Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, were closely tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. It is important to note that the costs for airborne surveys are very much dependent on the character, size, and conditions at each site; ordnance objectives of the survey (e.g. flight altitude); type of survey conducted (e.g. high-density or transects); and technology employed for the survey (e.g. total field magnetic) so that a universal formula cannot be fully developed. For this demonstration, the following table contains the cost elements that were tracked and documented for this demonstration. These costs include both operational and capital costs associated with system design and construction; salary and travel costs for support staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

Table 5.1- Survey Cost Assessment

Cost Category	Sub Category	Details	Quantity	Cost[1] (in dollars)
Pre-Survey (Start-up)	Site Characterization Mobilization	Site inspection (includes travel) Mission Plan preparation & logistics Calibration Site development (provided by ESTCP) Equipment/personnel transport (includes travel, preparation, packing, and transport) Helicopter/personnel transport (includes travel) Unpacking and system installation System testing & calibration	- 5 days - 2-1/2 days 3 days (25 hours airtime) 1 day 1 day	\$0 \$8,845 \$0 \$9,622 \$25,750 \$4,559 \$6,309
Pre-survey subtotal				\$55,085
	Cesium-vapor magnetometers GPS Booms and mounting hardware Orientation system Fluxgate magnetometer	\$122,200 total cost \$15,500 total cost \$36,500 total cost \$16,600 total cost \$5,300 total cost \$5,200 total cost	8 each 1 each 1 set 1 each 1 each 1 each	\$12,220 \$1,550 \$3,650 \$1,660 \$530 \$520

Capital Equipment[2]	Navigation system Laser Altimeter Data management console Magnetic base station GPS base station PCs for data processing & analysis Shipping Cases Trailer	$7,300 total cost $31,200 total cost $15,100 total cost $15,600 total cost $3,450 total cost $4,750 total cost $3,600 total cost	1 each 1 each 1 each 1 each 2 each 6 each 1 each	$730 $3,120 $1,510 $1,560 $345 $475 $360
Capital subtotal				$28,230
Operating Costs	Equipment Rental Data acquisition Operator labor Data processing Field support/management Maintenance Hotel and per diem Fuel Truck Airport Landing Fees Data analysis &	Spare magnetometers Helicopter time, including pilot and engineer labor Geophysicist Engineer Geosoft software maintenance[3] Survey team in New Mexico Remote re-fueling	2 each 7 days (52 hours airtime) 7 days 7 days (28 hours labor) 7 days (28 hours labor) 1 each 7 days 7 days 7 days	$2,540 $52,375 $1,750 $43,120 $43,120 $2,485 $3,514 $805 $175 $20,020

	interpretation Project management Reporting and documentation	Geophysicist	 13 days 8 days 12 days	$14,152 $16,412
Operating cost subtotal				$200,468
Post-Survey	Demobilization	Disassembly from helicopter, packing, and loading for transport Equipment/personnel transport (includes travel) Helicopter/personnel transport (includes travel)	1 day 2-1/2 days 3 days (25 hours airtime)	$4,559 $9,622 $25,750
Post-survey Subtotal				$39,931
Indirect Environmental Activity Costs	Environmental and Safety Training	8-hour HAZWOPR (includes the course cost)	8 hours	$4,309

Miscellaneous	Department of Energy Federal Acquisition Cost (FAC)	3% of project total; Congressionally-mandated charge for administering the Work-for-Others (WFO) program		$9,841
Total Costs				$337,864

[1]Includes all overhead and organization burden, fees, and associated taxes
[2]Capital costs are apportioned at 10% of the total cost for this project; all capital equipment was used for several projects during the course of the year in which this project occurred
[3]Geosoft software costs include the cost of 1 license and the UX-Detect module. The license cost is apportioned at 20% of the total cost for this project in a similar fashion to the capital equipment costs

6.0 Implementation Issues

6.1 Environmental Checklist

In order to operate, each system must have Federal Aviation Administration approval (Supplemental Type Certificate). The required testing and evaluation performed in Toronto before mobilization to New Mexico has been completed. In addition, ground crews are required to complete the 40-hour HAZWOPR course and to maintain their annual 8-hour refreshers for operation at most UXO sites.

6.2 Other Regulatory Issues

There are no additional regulatory requirements for operation at either site in New Mexico.

6.3 End-User Issues

The primary stakeholders for UXO issues at the Pueblo of Isleta sites in New Mexico are the members of the Pueblo of Isleta Tribe, other residents of Pueblo of Isleta Reservation, and State of New Mexico regulatory authorities. ORNL is currently supporting UXO activities at other sites with the Arrowhead system. Airborne UXO surveys are being designed to accommodate the limitations and needs of each site. Larger scale surveys have been proposed and discussed with several sites. USAESCH has assisted in efforts to commercialize the existing technology and this has led to shared operation with one contractor for engineering evaluation/cost analysis (EE/CA) activities. As new systems are developed and proven, they will enter into the same cycle of application and commercialization.

7.0 References

Doll, W. E., P. Hamlett, J. Smyre, D. Bell, J. E. Nyquist, T. J. Gamey, and J. S. Holladay, 1999, A field evaluation of airborne techniques for detection of unexploded ordnance. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, 1999, p. 773-782.

Doll, W. E., T.J. Gamey, and J.S. Holladay, 2001, Current Research into Airborne UXO detection, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Denver, CO, available on CD-ROM, 10 pgs.

Gamey, T. J., W. E. Doll, D. T. Bell, and J. S. Holladay, 2001, Current research into airborne UXO detection – Electromagnetics, UXO Forum, New Orleans, April 2001.

Gamey, T. J., W. E. Doll, A. Duffy, and D. S. Millhouse, 2000, Evaluation of improved airborne techniques for detection of UXO, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, p. 57-66.

McDonald, J.R. and H.H. Nelson, 1999, MTADS Live Site Demonstration at Pueblo of Isleta, N.M., Report no. NRL/PU/6110-00-398, August 1998.

Nelson, H.H., D. Wright, T. Furuya, J.R. McDonald, N. Khadr, and D.A. Steinhurst, 2004, MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February-2 March 2003: Naval Research Labs Report NRL/MR/6110—04-8764, 46 pp.

ORNL, 2004a, Final Report on 2002 Airborne Geophysical Survey at Pueblo of Laguna Bombing Targets, New Mexico: ESTCP Final Report, April 2004.

ORNL, 2004b, Final Report on 2002 Airborne Geophysical Survey at Aberdeen Proving Ground, Maryland: ESTCP Final Report, August 2004.

ORNL, 2004c, Final Report on Oak Ridge Airborne Geophysical System-Arrowhead Self Assessment: ESTCP Final Report, November 2004.

Swan, A.R.H. and M. Sandilands, 1995, Introduction to Geological Data Analysis, Blackwell Science, 446 pp.

Van, G.P., G. Calvert, L.P. Beard, T.J. Gamey, and A. M. Emond, 2004, Validation of Helicopter-Based Magnetic Survey at the Former Badlands Bombing Range: Expanded abstract in Proceedings of the Sixth Monterey Demining Symposium (MINWARA): Monterey, California, May 09-13, 2004.

Xia, J., W. Doll, R. Miller, and T. Gamey, 2002, A pseudo-adaptive hum filter to suppress rotor noise in high-resolution airborne magnetic data: Expanded abstract in Proceedings of the 72nd Annual International Meeting of the Society of Exploration Geophysicists, Salt Lake City, Utah, Oct 6-11, 2002, 4 pp., on CD-ROM.

8.0 Points of Contact

Points of contact are given below in Table 8.1.

Table 8.1: Points of Contact

Name	Organization	Phone	Project Role
Gary Jacobs	ORNL	865-574-7374	Division Director
David Bell	ORNL	865-574-2855, 865-250-0578 (cellular)	Project Manager
Bill Doll	ORNL	865-576-9930	Technical Manager
Jeff Gamey	ORNL	865-574-6316 865-599-0820 (cellular)	Operations Manager
Les Beard	ORNL	865-576-4646	Geophysicist
Abraham Emond	ORNL	865-576-5134	Geophysicist
Scott Millhouse	USAESCH	256-895-1607	Project Lead
Jim Piatt	Pueblo of Isleta	505-869-5748	Environment Department Director
Dan Munro	National Helicopters	905-893-2727	Helicopter Contractor President

Appendix A: Analytical Methods Supporting the Experimental Design

A.1 Statistically based UXO discrimination

We began investigating statistically-based discrimination methods after an analysis of dig results based on data collected at the former Badlands Bombing Range (BBR) in South Dakota showed statistical differences between ordnance and non-ordnance. In no instance was the statistical difference so strong that a single parameter could predict whether the source of an anomaly was UXO or not, but the possibility for discrimination increased as more parameters were considered. We used a routine developed to our specifications by Geosoft to rapidly identify and characterize anomalies above a given threshold from an analytical signal map. From these peaks we identified the associated magnetic field anomaly and sensor altitude, and computed a number of parameters that could be used directly or otherwise combined as statistically relevant predictors. From this point we used two different approaches for discrimination—a univariate and a multivariate methods.

A.1.1 Univariate method (used for Isleta 2003 data)

The univariate method relies on correlations from dig results based on airborne magnetic data collected at two different sites: an East Coast site and BBR. Both sites were geologically ‘clean’ in that neither contained basaltic rock or magnetic soils that could complicate any interpretations. We chose six parameters showing correlation with known UXO, and at each anomaly location evaluated whether the parameters fell within the range of the majority of known measured UXO. Each of the six parameters was scored zero if the parameter fell outside a specified range, and one if it fell within the range. For example, almost all ordnance in our known sample pool yielded peak-to-peak magnetic anomalies between 1.0 and 80 nT. Any anomaly falling outside this range was scored zero, as non-UXO. The six characteristics were scored and summed, so that items could have a value ranging from 6 (all characteristics in the range of UXO) to zero (all characteristics outside the range for UXO). The six parameters used in the univariate analysis were analytic signal amplitude, magnetic anomaly peak-to-peak magnitude, the distance between the magnetic anomaly peak and low, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the estimated source depth, and the angle between magnetic north and the line connecting the positive and negative lobes of the magnetic anomaly (denoted theta).

A.1.2 Multivariate method

Multivariate analysis should provide more information than the univariate approach described above as long as some or all of the variables are correlated, and if the number of known samples is large enough to obtain reliable statistics. The parameters must also be appropriately normalized to remove the effects of different magnitudes for the given parameters. We derived a vector of standard mean parameters $\boldsymbol{\mu}_0$ from a set of measurements over known ordnance items, and compute the symmetric covariance matrix $\mathbf{S}$ from the covariances computed for the different variable combinations. The statistical similarity between the known ordnance and the parameter vector **x** associated with an unknown is given by the Mahalanobis distance (Swan and Sandilands, 1995):

$$D = \{(\mathbf{x} - \boldsymbol{\mu}_0)^T \, \mathbf{S}^{-1} \, (\mathbf{x} - \boldsymbol{\mu}_0)\}^{1/2}. \qquad (1)$$

The smaller the Mahalanobis distance the more closely the unknown resembles ordnance from the known pool of items. The vectors **x** and $\boldsymbol{\mu}_0$ each have five entries: analytic signal peak, the magnitude of the negative lobe of the magnetic anomaly, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the ratio of the distance between the magnetic anomaly positive peak and the analytic signal peak to the instrument height added to the estimated source depth, and theta, as described in the univariate section. The differences in the variables used in the two methods of analysis occurred because the univariate analysis was done prior to a more complete statistical review of the data, which led to the multivariate approach.

A.2 Model-based inversion of magnetic data as an aid to discrimination

Magnetic fields in the vicinity of UXO can often be reliably estimated using a model based on a magnetic dipole. The MTADS-DAS software (McDonald and Nelson, 1999) is based on this model. MTADS-DAS does not perform discrimination, but rather is an aid to the interpreter, who subjectively performs the discrimination task. MTADS-DAS requires as input a set of coordinates (x,y,z) and a magnetic total field measurement at each coordinate. The software constructs a grid of the total field data from which the interpreter can select individual anomalies as likely UXO targets. The user selects a boundary around the anomaly that includes some area outside the main anomaly, and the MTADS-DAS code searches for a dipole model that best fits the selected data. Output are estimates of the moment of the magnetic dipole, its length, orientation, burial depth, and goodness of fit. From the returned parameters, an experienced interpreter can make a reasonably well-informed judgment as to whether or not the source of the anomaly is intact ordnance, scrap, or non-UXO related.

Appendix B: Quality Assurance Project Plan (QAPP)

At the time of this survey, we were not required to have a QAPP in place, nor had ESTCP published the current guidelines for QAPP documentation (ESTCP Final Report Guidance for UXO Projects, Revision 2, April 2002). We nevertheless developed our own QA/QC procedures that were followed through this and other projects. These fall into three main categories: operational QA/QC, system QA/QC, and data QA/QC.

Under the category of operational QA/QC:

- Site visit preliminary to survey to assess appropriateness of site for helicopter geophysical surveying;
- De-gaussing of helicopter rotor to decrease magnetic noise produced by this component;
- Review of GPS almanac to assess best times of the day for surveying;
- Emplacement of a calibration grid for daily system checks;
- A morning meeting to coordinate each day's activities;
- An evening meeting to review activities and safety issues.

Under the category of system QA/QC:

- Installation of booms under the supervision of the pilot and engineer, and subsequent double-checking of all mounts and bolts;
- Daily helicopter inspection and maintenance by pilot and engineer;
- Ground tests of system after installation (checks to determine if all magnetometers are operating and have been connected in the correct order, and an impulse test to determine the lag between magnetometers and fluxgate);
- An initial check flight after installation.

Under the category of data QA/QC:

- An extensive test flight to evaluate the effects of pitch, roll, and yaw on the magnetometers, from which we can calculate compensation coefficients, and to examine the high altitude noise levels of the magnetometers.
- Daily inspection of diurnal magnetic activity at a base station magnetometer;
- Visual inspection of all data;
- Daily plots of flight path and laser altitude;
- Adherence to the data processing flow, described in section 3.6.6;
- Daily production of digital magnetic maps;
- Archiving of all materials: flight logs, digital materials, and report.

Appendix C: Health and Safety Plan

This document represents the health and safety plan applied to field operations in New Mexico.

C.1 Aircraft Base of Operations

Albuquerque International Sunport
2200 Sunport Blvd. SE
Albuquerque, N.M. 87106
Fixed Base Operator: Cutter Flying Service, Inc.
Phone: 505-842-4184

The base of operations for all aircraft activities was Albuquerque International Sunport. The aircraft were stored and some refueling activities will occur at this location. Other refueling activities will occur remotely through use of a fuel truck provided by National Helicopters, Inc. No direct aircraft support (e.g., housing, fuelling, etc.) is requested from the Department of Defense.

C.2 Communications

Air-to-ground and ground-to-ground communications occurred using two-way VHF radios provided by ORNL and National Helicopters. Radios broadcasted at 118 - 135 MHz. All other communications were via cellular telephones.

C.3 Schedule Constraints and Crew Rest

C.3.1 Schedule Constraints

During aviation missions, activities can occur that are uncontrollable by the survey team and cause a delay of data acquisition. These activities may result in missed data acquisition windows or the loss of entire days of data acquisition.

C.3.2 Crew Rest

Crew rest will follow the guidelines prescribed by FAA regulations. Restrictions are placed on both the pilot's in-air flight-time and duty-time.

C.4 Aircraft

Bell 206L Long Ranger III Helicopter
Color scheme: White with midnight blue and light blue accents
Serial Number: 45784
Tail Number: C-CFLYC

National Helicopters, Inc.
11339 Albion Vaughn Road
Kleinburg, Ontario, Canada
Phone: 905-893-2727

C.5 Statement of Risks

Airborne geophysical surveys are designed to be conducted with minimal risk to personnel. Safe operation of the aircraft is the ***direct responsibility*** of the pilot, who will determine the minimum safe flight altitude and local weather conditions for safe flying on an ongoing basis. The mission was flown under all applicable Federal Regulations.

Most ground activities were limited to routine working conditions; however certain field activities will expose personnel to summer heat and prairie wildlife. Precautions against the heat include drinking plenty of water, using sunscreen, and taking breaks as needed. Precautions against the wildlife include wearing hiking (or similar) boots and minimization of exposure to that environment. In addition, the two-man rule was in effect for all on-site field activities.

For additional risk-related information, consult the Operational Emergency Response Plan contained in Appendix B of this document.

C.6 Emergency Notification

Emergency action plans are included in the Appendix of this document. In the event of an emergency, staff will first request assistance, then provide appropriate first aid measures until emergency assistance arrives. As soon as emergency assistance has been obtained, the following people were to be notified in sequence based on availability:

Mr. David Bell, ORNL Project Manager
Cellular: 865-250-0578
Office: 865-574-2855
Dr. Bill Doll, ORNL Technical Manager
Cellular: 865-599-0820
Office: 865-576-9930
Mr. Jeff Gamey, ORNL Operations Manager
Cellular: 865-599-0820
Office: 865-574-6316

Mr. Scott Millhouse, USAESCH Program Manager
Office: 256-895-1607
Mr. Dan Munro, National Helicopter, President
Office: 905-893-2727
Dr. Steve Hildebrand, ORNL Environmental Sciences Division Director
Office: 865-574-7374
Home: 865-966-6333

Each organizational member of the project team is responsible for flow-down of communications within the respective organization in the event of an incident or emergency (e.g. notification of next-of-kin by ORNL Environmental Sciences Division Director if ORNL staff is involved in an emergency situation, etc.). Any member of the project team, in the event of an emergency situation, shall **not** contact persons other than those designated in the above listing.

C.7 On-Site Ground Emergencies

In the event of an emergency that occurs on-site:

1) Telephone local emergency response organizations via 911, if needed.
2) Conduct appropriate first aid.
3) Notify managers, as listed above in sequence. **The ORNL Project Manager has jurisdiction for all on-site emergency activities.** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.
4) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
5) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.8 Off-Site Ground Emergencies

In the event of an emergency that occurs off-site:

1) Assess the urgency of the emergency.
2) Telephone local emergency response organizations via 911, if needed.
3) Conduct appropriate first aid while awaiting professional assistance.
4) Notify managers, as listed above in sequence. **The ORNL Project Manager has jurisdiction for all off-site emergency activities.** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.

5) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
6) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.9 In-Air Emergencies

In-air emergencies were to be handled via standard aircraft emergency protocol, including radio contact with the Rapid City Regional Airport. **<u>The pilot has jurisdiction for all emergency response activities and requirements when the aircraft is airborne.</u>** Follow-up telephone/radio notification to the emergency response personnel listed in Section 11.0 were to be made as soon as possible.

Appendix D: Data Storage and Archiving Procedures

General

Digital data are on the CD accompanying this report. Included are: (1) a copy of the final report in *.DOC format, (2) digital copies of the total field and analytic signal maps from the area flown (S-01) in TIF format, (3) dig lists in ASCII format, (4) geophysical data in ASCII format (zipped file), (5) ORNL analysis files, and (6) excavation and remediation results.

Geophysical Data

The data included with this report is ASCII text and conforms to the format described below. The file Isleta2003.xyz is provided on CD-ROM in zipped form as Isleta2003.zip. Coordinates are UTM Zone 13 N, NAD83 (Continental US).

ASCII text file format is comma delimited in the following order:

Column 1: Easting coord (m)
Column 2: Northing coord (m)
Column 3: Line ID (Example, 10010.2→ line 10010, sensor 2)
Column 4: laser altimeter (m)
Column 5: B-splined residual magnetic field

Dig Lists

The dig list information is saved in an ASCII text format file. Accompanying this document are ASCII files comprising target predictions for the entirety of S-01, and also for the portion of S-01 where a ground MTADS survey was performed. The target choices derive from multivariate statistical analysis of the total field and analytic signal data. Coordinates are given in UTM Zone 13 N (meters) using a NAD83 (Continental US) datum, as well as in geographical latitude/longitude.

TargetList_S01_.xyz— Targets generated over the entirety of S-01and prioritized 1-6 using multivariate statistical analysis according to likelihood of being UXO (1= highest likelihood, 6=lowest).

TargetList_S01_Subarea_mtads.xyz— Targets generated over the subarea of S-01 where ground MTADS data were collected. The targets were prioritized 1-6 using multivariate statistical analysis according to likelihood of being UXO (1= highest likelihood, 6=lowest).

Analysis files

Figure of Merit calculation file: Appendix H-fom.xls.

Images

Geophysical anomaly maps (total field residual and/or analytic signal), plus a flight height map for area S-01 are provided as image files in JPG formats. The TIF images have been saved at 200dpi at the scale labeled on each map. These files are labeled S01_TF.JPG, S01_AS.JPG, and S01_ALT.JPG.

Remediation Results

Government excavation results are provided in Excel files labeled:

Appendix E – Isleta excavation results

STRINGID	UTM_E	UTM_N	TYPE	Class	Item	Description	Area
81mm-40	318630.91	3858666.15	O	seed	81mm	IDA emplaced item	Air
81mm-4	318752.78	3858697.76	O	seed	81mm	IDA emplaced item	Air
81mm-38	318644.84	3858667.72	O	seed	81mm	IDA emplaced item	Air
81mm-37	318617.72	3858639.03	O	seed	81mm	IDA emplaced item	Air
81mm-35	318741.49	3858672.34	O	seed	81mm	IDA emplaced item	Air
81mm-34	318741.07	3858625.75	O	seed	81mm	IDA emplaced item	Air
81mm-33	318761.54	3858716.59	O	seed	81mm	IDA emplaced item	Air
81mm-32	318790.18	3858690.07	O	seed	81mm	IDA emplaced item	Air
81mm-28	318713.31	3858716.22	O	seed	81mm	IDA emplaced item	Air
81mm-27	318694.57	3858692.66	O	seed	81mm	IDA emplaced item	Air
81mm-25	318734.98	3858739.82	O	seed	81mm	IDA emplaced item	Air
81mm-24	318722.90	3858626.20	O	seed	81mm	IDA emplaced item	Air
81mm-23	318606.15	3858752.91	O	seed	81mm	IDA emplaced item	Air
81mm-22	318605.82	3858733.42	O	seed	81mm	IDA emplaced item	Air
81mm-20	318652.90	3858631.44	O	seed	81mm	IDA emplaced item	Air
81mm-19	318595.42	3858629.88	O	seed	81mm	IDA emplaced item	Air
81mm-18	318591.63	3858670.27	O	seed	81mm	IDA emplaced item	Air
81mm-17	318760.29	3858654.95	O	seed	81mm	IDA emplaced item	Air
81mm-15	318786.97	3858638.40	O	seed	81mm	IDA emplaced item	Air
81mm-13	318620.68	3858674.33	O	seed	81mm	IDA emplaced item	Air
81mm-12	318678.53	3858686.25	O	seed	81mm	IDA emplaced item	Air
81mm-11	318713.15	3858746.19	O	seed	81mm	IDA emplaced item	Air
81mm-10	318685.11	3858744.80	O	seed	81mm	IDA emplaced item	Air
60mm-9	318648.79	3858754.50	O	seed	60mm	IDA emplaced item	Air
60mm-8	318625.93	3858765.10	O	seed	60mm	IDA emplaced item	Air
60mm-7	318785.09	3858738.08	O	seed	60mm	IDA emplaced item	Air
60mm-5	318668.45	3858716.41	O	seed	60mm	IDA emplaced item	Air
60mm-20	318601.43	3858714.09	O	seed	60mm	IDA emplaced item	Air
60mm-10	318655.74	3858733.48	O	seed	60mm	IDA emplaced item	Air
2.75 in-7	318679.40	3858638.47	O	seed	2.75in	IDA emplaced item	Air
2.75 in-3	318639.93	3858653.36	O	seed	2.75in	IDA emplaced item	Air
2.75 in-11	318656.66	3858652.96	O	seed	2.75in	IDA emplaced item	Air
105mm-9	318716.10	3858697.60	O	seed	105mm	IDA emplaced item	Air
105mm-8	318703.32	3858663.09	O	seed	105mm	IDA emplaced item	Air
105mm-6	318698.21	3858716.48	O	seed	105mm	IDA emplaced item	Air
105mm-40	318660.04	3858675.80	O	seed	105mm	IDA emplaced item	Air
105mm-4	318780.88	3858707.31	O	seed	105mm	IDA emplaced item	Air
105mm-39	318617.11	3858701.08	O	seed	105mm	IDA emplaced item	Air
105mm-38	318603.74	3858687.01	O	seed	105mm	IDA emplaced item	Air
105mm-37	318600.16	3858651.80	O	seed	105mm	IDA emplaced item	Air
105mm-33	318766.93	3858634.84	O	seed	105mm	IDA emplaced item	Air
105mm-32	318766.86	3858683.86	O	seed	105mm	IDA emplaced item	Air
105mm-26	318679.25	3858702.47	O	seed	105mm	IDA emplaced item	Air
105mm-25	318712.02	3858639.44	O	seed	105mm	IDA emplaced item	Air
105mm-24	318731.11	3858640.41	O	seed	105mm	IDA emplaced item	Air
105mm-22	318633.82	3858732.77	O	seed	105mm	IDA emplaced item	Air

105mm-21	318593.34	3858764.31	O	seed	105mm	IDA emplaced item	Air
105mm-19	318751.70	3858747.66	O	seed	105mm	IDA emplaced item	Air
105mm-18	318705.72	3858758.87	O	seed	105mm	IDA emplaced item	Air
105mm-17	318676.65	3858757.50	O	seed	105mm	IDA emplaced item	Air
105mm-15	318684.27	3858626.11	O	seed	105mm	IDA emplaced item	Air
105mm-13	318784.26	3858665.55	O	seed	105mm	IDA emplaced item	Air
105mm-10	318643.79	3858689.54	O	seed	105mm	IDA emplaced item	Air
81mm-5	318558.66	3858751.25	O	seed	81mm	IDA emplaced item	Air
81mm-39	318560.50	3858738.99	O	seed	81mm	IDA emplaced item	Air
81mm-16	318562.60	3858663.77	O	seed	81mm	IDA emplaced item	Air
81mm-14	318561.88	3858701.61	O	seed	81mm	IDA emplaced item	Air
60mm-18	318576.57	3858691.99	O	seed	60mm	IDA emplaced item	Air
60mm-17	318558.01	3858680.28	O	seed	60mm	IDA emplaced item	Air
105mm-31	318582.15	3858728.72	O	seed	105mm	IDA emplaced item	Air
105mm-20	318584.08	3858751.11	O	seed	105mm	IDA emplaced item	Air
105mm-14	318562.59	3858725.15	O	seed	105mm	IDA emplaced item	Air
105mm-11	318587.34	3858712.95	O	seed	105mm	IDA emplaced item	Air
81mm-9	318625.14	3858554.84	O	seed	81mm	IDA emplaced item	Air
81mm-8	318603.33	3858571.68	O	seed	81mm	IDA emplaced item	Air
81mm-7	318666.67	3858544.68	O	seed	81mm	IDA emplaced item	Air
81mm-36	318619.64	3858596.86	O	seed	81mm	IDA emplaced item	Air
81mm-31	318668.18	3858520.37	O	seed	81mm	IDA emplaced item	Air
81mm-30	318682.35	3858573.38	O	seed	81mm	IDA emplaced item	Air
81mm-3	318733.15	3858490.35	O	seed	81mm	IDA emplaced item	Air
81mm-29	318664.45	3858480.22	O	seed	81mm	IDA emplaced item	Air
81mm-26	318686.33	3858521.99	O	seed	81mm	IDA emplaced item	Air
81mm-21	318628.36	3858528.98	O	seed	81mm	IDA emplaced item	Air
81mm-1	318731.78	3858581.76	O	seed	81mm	IDA emplaced item	Air
60mm-6	318640.94	3858508.42	O	seed	60mm	IDA emplaced item	Air
60mm-3	318764.50	3858521.33	O	seed	60mm	IDA emplaced item	Air
60mm-19	318754.60	3858484.14	O	seed	60mm	IDA emplaced item	Air
60mm-16	318665.85	3858584.78	O	seed	60mm	IDA emplaced item	Air
60mm-15	318696.43	3858566.38	O	seed	60mm	IDA emplaced item	Air
60mm-14	318690.62	3858507.48	O	seed	60mm	IDA emplaced item	Air
60mm-13	318650.82	3858568.33	O	seed	60mm	IDA emplaced item	Air
60mm-12	318689.42	3858541.96	O	seed	60mm	IDA emplaced item	Air
60mm-11	318708.74	3858477.64	O	seed	60mm	IDA emplaced item	Air
60mm-1	318741.40	3858546.48	O	seed	60mm	IDA emplaced item	Air
2.75 in-6	318778.36	3858584.90	O	seed	2.75in	IDA emplaced item	Air
2.75 in-5	318624.34	3858608.55	O	seed	2.75in	IDA emplaced item	Air
2.75 in-4	318664.75	3858608.27	O	seed	2.75in	IDA emplaced item	Air
2.75 in-2	318662.66	3858506.78	O	seed	2.75in	IDA emplaced item	Air
105mm-7	318679.53	3858496.76	O	seed	105mm	IDA emplaced item	Air
105mm-5	318782.01	3858478.72	O	seed	105mm	IDA emplaced item	Air
105mm-36	318615.84	3858617.53	O	seed	105mm	IDA emplaced item	Air
105mm-35	318594.06	3858599.61	O	seed	105mm	IDA emplaced item	Air
105mm-34	318618.11	3858512.88	O	seed	105mm	IDA emplaced item	Air
105mm-30	318706.58	3858582.12	O	seed	105mm	IDA emplaced item	Air
105mm-29	318678.95	3858556.37	O	seed	105mm	IDA emplaced item	Air

105mm-28	318646.66	3858551.67	O	seed	105mm	IDA emplaced item	Air
105mm-27	318623.45	3858581.11	O	seed	105mm	IDA emplaced item	Air
105mm-23	318717.19	3858603.19	O	seed	105mm	IDA emplaced item	Air
105mm-2	318777.91	3858553.34	O	seed	105mm	IDA emplaced item	Air
105mm-16	318646.99	3858531.01	O	seed	105mm	IDA emplaced item	Air
105mm-12	318778.50	3858619.72	O	seed	105mm	IDA emplaced item	Air
105mm-1	318761.89	3858579.30	O	seed	105mm	IDA emplaced item	Air
81mm-6	318562.77	3858496.19	O	seed	81mm	IDA emplaced item	Air
81mm-2	318578.10	3858579.80	O	seed	81mm	IDA emplaced item	Air
60mm-4	318580.54	3858517.97	O	seed	60mm	IDA emplaced item	Air
60mm-2	318561.97	3858538.17	O	seed	60mm	IDA emplaced item	Air
2.75 in-9	318567.73	3858567.94	O	seed	2.75in	IDA emplaced item	Air
2.75 in-8	318568.21	3858553.20	O	seed	2.75in	IDA emplaced item	Air
2.75 in-12	318558.31	3858594.66	O	seed	2.75in	IDA emplaced item	Air
2.75 in-10	318550.19	3858570.43	O	seed	2.75in	IDA emplaced item	Air
2.75 in-1	318561.73	3858525.05	O	seed	2.75in	IDA emplaced item	Air
105mm-3	318586.68	3858549.42	O	seed	105mm	IDA emplaced item	Air
AS1-294	318653.55	3858721.80	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-370	318728.73	3858702.87	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-282	318729.14	3858655.25	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-375	318690.47	3858603.85	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-376	318778.06	3858549.11	O	dig	Nuclear SIM	Unknown, Possible Nuclear Simulator	Air
AS1-377	318726.89	3858494.41	O	dig	Frag	AN/M64 Bomb Body Fragments	Air
AS1-382	318756.13	3858363.41	O	dig	1000lb Bomb	Bomb, AN/M64 1000#	Air
AS1-387	318770.18	3858229.09	O	dig	Nuclear SIM	Unknown, Possible Nuclear Simulator	Air
AS1-280	318589.31	3857585.20	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-281	318602.00	3857584.93	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-271	318755.09	3857583.29	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-278	318598.31	3857581.06	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-276	318616.91	3857574.66	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-277	318598.15	3857573.77	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-305	318593.52	3857572.11	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-235	318553.67	3857570.11	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-240	318571.81	3857569.42	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-238	318538.96	3857569.32	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-392	318725.87	3857568.69	O	dig	Nuclear SIM	Unknown, Possible Nuclear Simulator	Air
AS1-274	318723.88	3857567.78	O	dig	Nuclear SIM	Unknown, Possible Nuclear Simulator	Air

AS1-269	318748.65	3857567.14	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-234	318550.63	3857566.10	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-256	318665.03	3857565.93	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-268	318752.71	3857565.37	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-252	318619.96	3857564.39	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-237	318539.63	3857563.46	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-348	318662.78	3857563.04	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-232	318554.62	3857563.02	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-262	318697.43	3857562.08	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-259	318681.23	3857561.93	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-236	318548.13	3857560.55	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-366	318653.75	3857560.18	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-250	318609.63	3857559.90	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-233	318552.64	3857559.68	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-258	318679.45	3857559.48	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-367	318672.60	3857559.29	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-265	318739.75	3857559.27	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-362	318578.25	3857557.59	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-249	318604.62	3857557.43	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-253	318632.99	3857557.18	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-231	318561.33	3857557.12	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-246	318602.13	3857555.32	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-328	318688.72	3857554.95	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-264	318734.59	3857554.67	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-230	318552.48	3857554.33	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-248	318610.96	3857553.24	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-220	318527.20	3857553.04	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-363	318587.87	3857552.82	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-224	318536.33	3857552.69	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-213	318512.48	3857552.16	O	dig	Frag	M38 Bomb Body	Air

						Fragments	
AS1-254	318634.75	3857551.95	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-219	318525.47	3857551.24	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-243	318586.96	3857550.77	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-212	318510.66	3857550.13	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-229	318555.16	3857550.13	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-218	318521.36	3857549.94	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-241	318578.28	3857549.82	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-211	318508.45	3857549.65	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-228	318562.18	3857548.84	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-239	318570.17	3857548.43	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-216	318512.89	3857548.13	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-247	318613.69	3857547.45	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-222	318532.79	3857546.09	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-217	318519.12	3857545.30	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-223	318535.81	3857544.72	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-227	318553.28	3857543.87	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-221	318532.53	3857543.76	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-190	318571.62	3857542.76	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-214	318506.93	3857542.46	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-226	318548.69	3857541.62	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-365	318659.82	3857541.16	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-215	318514.95	3857541.01	O	dig	Missile Warhead	CLAMP, Missile Warhead	Air
AS1-225	318545.97	3857541.00	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-188	318584.29	3857539.64	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-199	318523.93	3857539.04	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-327	318664.85	3857537.63	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-198	318534.78	3857535.33	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-197	318534.78	3857535.33	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-203	318508.83	3857535.28	O	dig	Frag	M38 Bomb Body	Air

						Fragments	
AS1-187	318575.28	3857533.17	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-196	318540.47	3857531.98	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-345	318680.98	3857531.81	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-202	318512.40	3857530.56	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-189	318566.78	3857529.66	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-173	318752.24	3857528.32	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-360	318680.69	3857527.60	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-184	318584.75	3857525.84	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-200	318522.07	3857525.35	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-191	318558.90	3857523.39	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-201	318517.54	3857521.46	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-195	318549.70	3857521.26	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-192	318556.36	3857520.31	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-207	318507.28	3857519.78	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-178	318674.72	3857519.72	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-193	318564.73	3857516.78	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-180	318636.02	3857514.73	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-194	318549.89	3857514.48	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-361	318641.25	3857513.50	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-149	318522.03	3857510.16	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-148	318506.24	3857509.74	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-164	318658.02	3857506.98	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-163	318650.86	3857506.83	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-158	318562.43	3857506.04	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-150	318527.17	3857505.91	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-160	318582.41	3857505.82	O	dig	1000lb Bomb	Bomb, AN/M64 1000#	Air
AS1-155	318549.54	3857505.20	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-343	318742.29	3857503.82	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-157	318559.02	3857501.51	O	dig	Frag	M38 Bomb Body Fragments	Air

AS1-321	318609.70	3857499.73	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-152	318523.46	3857498.09	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-159	318567.64	3857497.97	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-320	318571.07	3857495.48	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-359	318629.56	3857494.23	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-151	318519.35	3857493.78	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-161	318609.76	3857491.90	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-156	318560.53	3857491.79	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-153	318521.04	3857491.36	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-139	318641.03	3857490.72	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-144	318525.32	3857486.70	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-132	318585.47	3857483.55	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-138	318630.62	3857483.14	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-129	318508.03	3857481.62	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-137	318620.01	3857479.69	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-144	318748.41	3857478.90	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-135	318611.56	3857478.81	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-143	318745.37	3857477.89	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-133	318592.71	3857477.87	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-130	318557.93	3857477.60	O	dig	MK-81	Bomb, Mk-81 Low Drag Practice	Air
AS1-145	318757.13	3857477.50	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-131	318584.25	3857475.15	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-128	318516.62	3857474.83	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-340	318654.89	3857474.59	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-134	318595.06	3857474.25	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-141	318672.60	3857472.25	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-126	318508.20	3857470.18	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-120	318644.69	3857466.47	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-127	318506.59	3857466.07	O	dig	Burster Cup	Burster Cup, M38 Bomb	Air
AS1-108	318542.12	3857465.48	O	dig	500lb Bomb	AN/M57 500# Bomb	Air

AS1-122	318686.38	3857462.89	O	dig	M38	Bomb, M38 Practice	Air
AS1-338	318640.14	3857462.83	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-115	318605.19	3857462.36	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-109	318586.12	3857460.59	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-119	318643.35	3857460.00	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-121	318684.55	3857459.01	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-356	318576.32	3857457.16	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-114	318610.43	3857456.80	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-110	318590.03	3857456.30	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-337	318607.42	3857455.94	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-111	318595.10	3857455.93	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-117	318635.97	3857453.23	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-125	318736.62	3857451.58	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-318	318657.07	3857451.11	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-116	318631.41	3857450.76	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-112	318606.23	3857449.95	O	dig	M38	Bomb, M38 Practice	Air
AS1-357	318668.27	3857447.44	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-113	318614.79	3857446.60	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-107	318549.17	3857444.49	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-339	318681.40	3857438.49	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-118	318649.53	3857438.28	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-316	318734.48	3857433.44	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-105	318503.25	3857433.29	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-317	318683.05	3857430.42	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-95	318593.64	3857430.03	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-100	318522.52	3857427.05	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-99	318553.23	3857426.54	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-90	318710.20	3857424.85	O	dig	M38	Bomb, M38 Practice	Air
AS1-91	318702.64	3857423.95	O	dig	Frag	Bomb Fragment	Air
AS1-97	318565.15	3857422.32	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-93	318680.59	3857422.30	O	dig	Frag	M38 Bomb Body Fragments	Air

AS1-102	318507.88	3857421.49	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-92	318678.17	3857418.82	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-101	318515.70	3857417.83	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-82	318660.67	3857415.75	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-80	318642.85	3857414.46	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-98	318562.53	3857413.76	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-89	318724.80	3857413.27	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-87	318751.61	3857412.95	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-73	318581.06	3857411.78	O	dig	M38	Bomb, M38 Practice	Air
AS1-84	318714.23	3857411.32	O	dig	MK-83	Bomb, MK-83 Low Drag	Air
AS1-81	318659.21	3857411.12	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-72	318550.87	3857409.71	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-79	318637.85	3857408.30	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-355	318735.31	3857405.96	O	dig	MK-23	Bomb, MK-23 MOD-1 Practice	Air
AS1-77	318619.48	3857402.26	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-78	318652.20	3857400.28	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-83	318715.91	3857399.22	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-185	318735.67	3857398.93	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-66	318574.23	3857391.39	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-76	318616.35	3857391.08	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-65	318605.62	3857386.37	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-67	318569.52	3857385.82	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-59	318724.17	3857384.66	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-64	318627.42	3857384.47	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-55	318732.05	3857383.54	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-62	318642.81	3857380.65	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-63	318638.33	3857379.28	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-68	318551.48	3857377.86	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-58	318726.79	3857376.38	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-57	318723.72	3857375.64	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-60	318657.98	3857374.78	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-61	318668.41	3857373.34	O	dig	Frag	M38 Bomb Body	Air

						Fragments	
AS1-71	318503.09	3857372.84	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-70	318562.67	3857369.06	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-69	318557.55	3857367.89	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-46	318595.87	3857366.49	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-56	318727.54	3857365.52	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-313	318632.49	3857359.86	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-45	318562.32	3857358.38	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-50	318713.39	3857353.38	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-44	318562.60	3857350.22	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-52	318713.63	3857347.99	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-48	318636.19	3857346.24	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-311	318730.93	3857335.18	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-39	318552.10	3857326.86	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-309	318702.94	3857325.18	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-310	318714.42	3857324.57	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-41	318712.44	3857318.07	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-38	318522.66	3857317.02	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-42	318736.37	3857315.29	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-35	318682.20	3857310.54	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-34	318698.40	3857309.53	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-33	318688.06	3857303.61	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-32	318697.68	3857302.68	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-36	318555.07	3857300.75	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-31	318710.95	3857293.97	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-24	318526.44	3857287.87	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-37	318517.01	3857287.58	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-353	318677.16	3857284.53	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-28	318630.90	3857277.06	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-29	318644.30	3857276.50	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-26	318573.25	3857270.26	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-23	318500.90	3857269.21	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-27	318620.35	3857266.08	O	dig	500lb Bomb	AN/M57 500# Bomb	Air
AS1-25	318540.91	3857262.60	O	dig	Frag	M38 Bomb Body	Air

						Fragments	
AS1-20	318662.87	3857259.78	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-334	318587.21	3857253.42	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-22	318554.85	3857250.30	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-19	318674.57	3857246.04	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-21	318583.92	3857245.07	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-18	318698.84	3857239.87	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-13	318531.92	3857233.18	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-352	318730.27	3857231.96	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-12	318499.19	3857223.81	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-16	318696.09	3857221.95	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-332	318741.86	3857218.69	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-14	318628.79	3857212.68	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-17	318729.12	3857211.47	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-11	318604.65	3857203.21	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-9	318660.43	3857197.13	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-10	318666.17	3857193.70	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-8	318728.54	3857192.14	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-6	318715.57	3857185.84	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-1	318510.23	3857181.50	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-2	318532.68	3857178.03	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-4	318674.28	3857174.27	O	dig	MK-76	MK-76 Practice Bomb	Air
AS1-3	318577.46	3857172.90	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-5	318691.35	3857166.30	O	dig	Frag	M38 Bomb Body Fragments	Air
AS1-350	318605.57	3858733.54	C	dig	Geology	Magnetic Soil	Air
AS1-336	318735.23	3857389.12	C	dig	Scrap	Wire	Air
AS1-314	318671.99	3857384.70	C	dig	Geology	Magnetic Rock	Air
AS1-47	318599.14	3857364.06	C	dig	Scrap	Wire	Air
AS1-51	318709.64	3857356.76	C	dig	Scrap	Pipe	Air
AS1-312	318628.18	3857346.49	C	dig	Scrap	Wire	Air
AS1-49	318704.14	3857346.41	C	dig	Scrap	Oil Filter	Air
AS1-354	318685.20	3857346.41	C	dig	Scrap	Tin Can	Air
AS1-53	318745.95	3857341.15	C	dig	Scrap	Tin Cans	Air
AS1-43	318749.69	3857329.61	C	dig	Scrap	Tin Can	Air
AS1-40	318674.59	3857328.66	C	dig	Scrap	Tin Can Fragments	Air
AS1-308	318697.41	3857313.94	C	dig	Scrap	Tin Cans	Air

AS1-30	318739.02	3857282.27	C	dig	Scrap	Tin Can	Air
AS1-331	318619.70	3857234.04	C	dig	Geology	Magnetic Rock	Air
AS1-15	318639.74	3857224.24	C	dig	Geology	Magnetic Rock	Air
S1A-95	318453.11	3859234.79	O	dig	500lb Bomb	72in snake eye fins 96in Bomb GP 500lbs	3sys
S1A-141	318097.20	3859172.44	O	dig	1000lb Bomb	AN/M 64 1000 # Bomb	3sys
S1A-182	318206.14	3858610.61	O	dig	BDU	BDU found at 38in	3sys
S1A-66	318227.19	3858787.92	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-3	318495.85	3859054.04	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-115	318128.12	3858740.39	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-12	318162.92	3858747.72	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-31	318336.81	3858554.47	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-70	318434.01	3858764.24	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-1	318482.36	3859051.98	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-28	318218.14	3858685.82	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-65	318255.61	3858664.81	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-15	318201.26	3858847.65	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-9	318061.71	3858783.47	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-108	318391.63	3858672.30	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-44	318462.61	3859093.51	O	dig	Frag	M-38 Bomb body fragments	3sys
S1A-50	318073.28	3858713.36	O	dig	Frag	M-38 Bomb fragments	3sys
S1A-158	318059.32	3858672.18	O	dig	Frag	M-38 Bomb fragments	3sys
S1A-100	318068.09	3858718.19	O	dig	Frag	M-38 Bomb fragments	3sys
S1A-60	318393.29	3858800.44	O	dig	Frag	M-38 fragment at 0.0 ft	3sys
S1A-99	318110.41	3858779.14	O	dig	Frag	M-38 fragments	3sys
S1A-17	318199.80	3858540.09	O	dig	Frag	M-38 fragments	3sys
S1A-135	318438.57	3858534.19	O	dig	Frag	M-38 fragments	3sys
S1A-40	318411.50	3858520.15	O	dig	Frag	M-38 fragments	3sys
S1A-38	318158.53	3859308.94	O	dig	Frag	M-38 fragments	3sys
S1A-55	318272.63	3859305.65	O	dig	Frag	M-38 fragments	3sys
S1A-16	318187.75	3858553.04	O	dig	Frag	M-38 fragments	3sys
S1A-58	318406.75	3859390.72	O	dig	Frag	M-38 fragments	3sys
S1A-10	318108.67	3858674.08	O	dig	Frag	M-38 fragments	3sys
S1A-21	318355.47	3858708.97	O	dig	Frag	M-38 fragments	3sys
S1A-169	318437.20	3859441.55	O	dig	Frag	M-38 fragments	3sys
S1A-123	318411.12	3859397.42	O	dig	Frag	M-38 fragments	3sys
S1A-11	318080.87	3858588.90	O	dig	Frag	M-38 fragments	3sys
S1A-181	318163.96	3858657.56	O	dig	Frag	M-38 fragments	3sys
S1A-19	318323.43	3858760.12	O	dig	Frag	M-38 fragments	3sys

S1A-52	318167.14	3858577.49	O	dig	Frag	M-38 fragments	3sys
S1A-18	318238.09	3858766.97	O	dig	Frag	M-38 fragments	3sys
S1A-20	318297.78	3858724.85	O	dig	Frag	M-38 fragments	3sys
S1A-241	318530.62	3858737.96	O	dig	Frag	M-38 fragments	3sys
S1A-54	318252.31	3858744.70	O	dig	Frag	M-38 fragments	3sys
S1A-49	318511.48	3858930.52	O	dig	Frag	M-38 fragments	3sys
S1A-45	318449.19	3859049.48	O	dig	Frag	M-38 fragments	3sys
S1A-138	318466.06	3859051.58	O	dig	Frag	M-38 fragments	3sys
S1A-87	318424.36	3859056.28	O	dig	Frag	M-38 fragments	3sys
S1A-244	318498.21	3858934.11	O	dig	Frag	M-38 fragments	3sys
S1A-263	318383.63	3858973.76	O	dig	Frag	M-38 fragments	3sys
S1A-69	318377.25	3859021.89	O	dig	Frag	M-38 fragments	3sys
S1A-121	318464.62	3859056.54	O	dig	Frag	M-38 fragments	3sys
S1A-103	318207.35	3859176.81	O	dig	Frag	M-38 fragments	3sys
S1A-32	318334.56	3859180.87	O	dig	Frag	M-38 fragments	3sys
S1A-6	318041.02	3859223.57	O	dig	Frag	M-38 fragments	3sys
S1A-13	318147.66	3859059.50	O	dig	Frag	M-38 fragments	3sys
S1A-107	318342.64	3859063.94	O	dig	Frag	M-38 fragments	3sys
S1A-178	318050.36	3859254.05	O	dig	Frag	M-38 fragments	3sys
S1A-8	318104.73	3858871.17	O	dig	Frag	M-38 fragments	3sys
S1A-5	318037.22	3858909.02	O	dig	Frag	M-38 fragments	3sys
S1A-157	318072.71	3858838.84	O	dig	Frag	M-38 fragments	3sys
S1A-128	318202.13	3858595.34	O	dig	Frag	M-38 fragments @ surface M-38 fragments also found @ 24in	3sys
S1A-111	318034.52	3858624.86	O	dig	Frag	M-38 fragments 17in nocth 13in depth of the inxin mark hot soil @ 5'	3sys
S1A-22	318396.83	3858679.63	O	dig	Frag	M-38 fragments at 18in	3sys
S1A-23	318510.90	3858579.82	O	dig	Frag	M-38 fragments at 2.9(ft)	3sys
S1A-33	318376.08	3858768.39	O	dig	Frag	M-38 fragments at 32in	3sys
S1A-47	318522.14	3858605.71	O	dig	Frag	M-38 fragments found at 2.5(ft)	3sys
S1A-24	318518.64	3858614.11	O	dig	Frag	M-38 fragments found at 8 ft.	3sys
S1A-197	318061.30	3858672.32	O	dig	Frag	M-38 spot Initiator	3sys
S1A-118	318288.23	3858551.92	O	dig	Missile Comp	Missile components unknown 12'x 12' x 5' D pit	3sys
S1A-149	318011.34	3858581.89	O	dig	MK-76	MK-76	3sys
S1A-159	318057.42	3858664.09	O	dig	MK-76	MK-76	3sys
S1A-71	318429.90	3859184.01	O	dig	MK-76	MK-76	3sys
S1A-86	318355.15	3858812.10	O	dig	MK-76	MK-76 @ 30in D Hot rock @ 52in	3sys
S1A-105	318276.37	3859018.58	O	dig	Frag	Nuke simulator fragments	3sys
S1A-94	318450.98	3858543.66	O	dig	Frag	Large cylinder body with fragments of steel and aluminum	3sys
S1A-64	318231.07	3858578.59	O	dig	Frag	M-38 Fin	3sys
S1A-168	318425.55	3859385.28	C	dig	Scrap	24in pipe with heavy driving point	3sys

S1A-140	318426.57	3859367.12	C	dig	Scrap	36in pipe vertical 18in above surface	3sys
S1A-137	318469.85	3858814.30	C	dig	Scrap	4' 6in pipe	3sys
S1A-243	318070.72	3858713.47	C	dig	Geology	A magnetic rock	3sys
S1A-120	318340.50	3859331.65	C	dig	Scrap	Approximately 50 ft of tangled commo wire on surface; no find @ depth.	3sys
S1A-227	318443.52	3858621.95	C	dig	Geology	A Rock	3sys
S1A-113	318040.93	3859424.17	C	dig	Scrap	Barbed wire	3sys
S1A-77	318133.24	3859470.78	C	dig	Scrap	Barbed wire 36in long @ surface No find @ depth	3sys
S1A-142	318463.53	3858908.53	C	dig	Geology	Big magnetic rock	3sys
S1A-187	318313.40	3859441.28	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-42	318528.88	3859145.70	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-2	318469.06	3859128.72	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-36	318478.93	3859121.71	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-196	318310.05	3859397.43	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-164	318308.33	3859396.12	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-252	318322.40	3859379.44	C	dig	Scrap	Commo wire @ surface no find @ depth.	3sys
S1A-104	318236.38	3858608.83	C	dig	Geology	Found at 16in dug to 27in nothing found below 16in	3sys
S1A-201	318263.81	3858930.90	C	dig	Geology	Hot Rock	3sys
S1A-306	318272.39	3858519.67	C	dig	Geology	Hot Rock	3sys
S1A-80	318321.49	3859171.99	C	dig	Geology	Hot rock	3sys
S1A-286	318263.53	3859141.20	C	dig	Geology	Hot Rock	3sys
S1A-309	318324.55	3858791.14	C	dig	Geology	Hot Rock	3sys
S1A-179	318184.35	3858764.37	C	dig	Geology	Hot Rock	3sys
S1A-225	318270.34	3858760.83	C	dig	Geology	Hot Rock	3sys
S1A-303	318316.32	3858913.10	C	dig	Geology	Hot Rock	3sys
S1A-315	318231.94	3858825.61	C	dig	Geology	Hot Rock	3sys
S1A-283	318262.53	3858628.36	C	dig	Geology	Hot Rock	3sys
S1A-307	318275.43	3858863.57	C	dig	Geology	Hot Rock @ 42in D	3sys
S1A-209	318312.63	3858924.20	C	dig	Geology	Hot Rock on surface to 32in D	3sys
S1A-285	318301.39	3858924.87	C	dig	Geology	Hot Rocks	3sys
S1A-110	318518.81	3858539.71	C	dig	Geology	Hot rocks	3sys
S1A-191	318396.73	3858814.52	C	dig	Geology	Hot rocks @ 36in-65in	3sys
S1A-93	318165.06	3858604.62	C	dig	Geology	Hot soil	3sys
S1A-264	318439.60	3858644.52	C	dig	Geology	Hot soil	3sys
S1A-270	318396.26	3858825.98	C	dig	Geology	Hot soil	3sys
S1A-234	318502.99	3858878.38	C	dig	Geology	Hot soil	3sys
S1A-206	318280.89	3858864.67	C	dig	Geology	Hot soil	3sys
S1A-289	318302.27	3858831.68	C	dig	Geology	Hot soil- 4ft Dig	3sys
S1A-122	318184.06	3858689.96	C	dig	Scrap	Kitchen knife on surface	3sys
S1A-214	318466.84	3858718.47	C	dig	Geology	Magnetic rock	3sys

S1A-109	318487.98	3858830.04	C	dig	Geology	Magnetic rock	3sys
S1A-167	318356.46	3858770.87	C	dig	Geology	Magnetic soil	3sys
S1A-211	318019.43	3858604.20	C	dig	Geology	magnetic soil	3sys
S1A-245	318181.97	3858807.10	C	dig	Geology	magnetic soil	3sys
S1A-134	318434.29	3858538.40	C	dig	Geology	Magnetic soil	3sys
S1A-319	318023.16	3858530.87	C	dig	Geology	magnetic soil	3sys
S1A-226	318263.46	3858787.60	C	dig	Geology	magnetic soil	3sys
S1A-298	318455.99	3858746.42	C	dig	Geology	Magnetic soil	3sys
S1A-147	317998.06	3858576.92	C	dig	Geology	magnetic soil	3sys
S1A-193	318431.69	3858792.67	C	dig	Geology	Magnetic soil	3sys
S1A-124	318469.30	3858562.75	C	dig	Geology	Magnetic soil @ 5.2 ft	3sys
S1A-246	318434.09	3858793.74	C	dig	Geology	Magnetic soil; steady tone no significant increase	3sys
S1A-73	318500.76	3858921.13	C	dig	Scrap	Metal band	3sys
S1A-175	318009.63	3859231.00	C	dig	Scrap	Metal bucket	3sys
S1A-102	318135.00	3859368.23	C	dig	Scrap	Metal bucket	3sys
S1A-25	318015.23	3859230.92	C	dig	Scrap	Metal bucket	3sys
S1A-7	318078.16	3859190.92	C	dig	Scrap	Metal bucket	3sys
S1A-148	318133.48	3859296.14	C	dig	Scrap	Metal bucket	3sys
S1A-26	318004.05	3859232.61	C	dig	Scrap	Metal bucket	3sys
S1A-155	318057.67	3859256.17	C	dig	Scrap	Metal bucket	3sys
S1A-48	318461.20	3858921.02	C	dig	Scrap	Metal bucket	3sys
S1A-4	318473.81	3859072.39	C	dig	Scrap	Metal can	3sys
S1A-136	318416.27	3859153.13	C	dig	Scrap	Metal Pan	3sys
S1A-43	318457.72	3858927.25	C	dig	Scrap	Metal pan	3sys
S1A-176	318012.18	3859258.78	C	dig	Scrap	Metal plate	3sys
S1A-81	318302.24	3858919.13	C	dig	Scrap	Metal wire	3sys
S1A-82	318368.30	3859050.81	C	dig	Geology	Rock	3sys
S1A-154	318077.03	3859281.93	C	dig	Scrap	Sheet metal	3sys
S1A-177	318047.40	3859396.58	C	dig	Scrap	Sheet metal	3sys
S1A-114	318060.85	3859314.20	C	dig	Scrap	Sheet metal	3sys
S1A-153	318060.47	3859281.56	C	dig	Scrap	Sheet metal	3sys
S1A-98	318036.26	3859419.97	C	dig	Scrap	Sheet metal	3sys
S1A-170	318212.81	3859413.99	C	dig	Scrap	Sheet metal	3sys
S1A-97	318019.51	3859313.94	C	dig	Scrap	Steel coffee pot	3sys
S1A-233	318287.72	3858659.39	C	dig	Scrap	Steel wire	3sys
S1A-27	318038.58	3859287.50	C	dig	Scrap	Stove pipe	3sys
S1A-59	318382.34	3859039.42	C	dig	Scrap	Wire	3sys
S1A-91	318527.38	3859144.08	C	dig	Scrap	Wire	3sys
S1A-205	318190.06	3858669.35	C	dig	Scrap	Wire	3sys
S1A-139	318247.12	3858562.05	C	dig	Scrap	Wire	3sys
S1A-51	318137.13	3858538.82	C	dig	Scrap	Wire	3sys
S1A-133	318306.12	3858512.88	C	dig	Scrap	Wire 12qa	3sys
S1A-129	318278.46	3858520.35	C	dig	Scrap	Wire 12qa	3sys
S1A-202	318296.52	3858521.20	C	dig	Scrap	Wire 12qa	3sys
S1A-29	318267.12	3858573.00	C	dig	Scrap	Wire 12qa	3sys
S1A-189	318348.83	3859201.64	C	dig	Scrap	Wire 12qa	3sys
S1A-220	318241.03	3859258.42	C	dig	Scrap	Wire on surface	3sys
S1A-112	318041.45	3858893.01	C	dig	Scrap	Wire on surface no find @ depth	3sys

Appendix F: Vehicular MTADS/ORNL Airborne Dig List.xls,
Appendix G: ThreeSystem_ORNL1.xls.